FACULTEIT ECONOMISCHE EN
TOEGEPASTE ECONOMISCHE
WETENSCHAPPEN

KATHOLIEKE
UNIVERSITEIT
LEUVEN

ECONOMIC ANALYSIS OF TRAFFIC SAFETY

Proefschrift voorgedragen
tot het behalen van de graad
van Doctor in de
Economische Wetenschappen

door

Eef DELHAYE

Nummer 256 2007

Doctoral Commission

Supervisor: Prof. Dr. Stef Proost (K.U.Leuven)

Members: Prof. Dr. Bruno De Borger (Universiteit Antwerpen)

Prof. Dr. Dirk Heremans (K.U.Leuven)

Prof. Dr. Erik Schokkaert (K.U.Leuven)

Prof. Dr. Erik Verhoef (Vrije Universiteit Amsterdam)

Woord Vooraf

"I read part of it all the way through"

(S. Goldwyn)

Het schrijven van een voorwoord van een doctoraat is – net als het schrijven van het doctoraat zelf – een werk van lange adem. Of het zou dit toch moeten zijn. Want, in tegenstelling tot het doctoraat zelf, wordt het voorwoord door bijna iedereen gelezen die het doctoraat in zijn handen krijgt. Naast de inhoud, de kleur van het kaft, enzovoort moet er dus goed over nagedacht worden. Jammer genoeg is het voorwoord ook dat deel van het doctoraat dat helemaal op het einde geschreven wordt en daardoor ontbreekt meestal de tijd om er lang aan te schaven.

Een voorwoord is ook de plaats voor vergelijkingen. Velen vergelijken het schrijven van een doctoraat met 'iets': een lange reis, een wielerwedstrijd of een spel. Om in deze traditie te blijven, wou ik het schrijven van een doctoraat vergelijken met het spelen van het spel Carcasson. De idee was dat je langzaam maar zeker bouwt aan je kastelen (papers) en wegen (ideeën), je een boer legt in de buurt van een interessant kasteel. Maar soms raakt een kasteel niet af of blijkt het toch iets kleiner te zijn dan verwacht. Het verschil met Carcasson is dat je niet alleen staat in je spel. Je speelt met een heel team: je promotor, de commissie, de collega's, familie en vrienden: allemaal staan ze klaar om je te helpen, de juiste zet te suggereren,… en belangrijker: je eventjes van het spelletje weg te trekken zodat je het overzicht bewaart. Maar dan vroeg ik me af of iedereen dit spel en de subtiliteiten ervan wel kende en besloot ik die vergelijking maar te schrappen. Of staat ze er nu toch in?

Want in de eerste plaats is een voorwoord een dankwoord. En het is niet zomaar een dankwoord! Aangezien iedereen zeker dit stukje leest, is het belangrijk om even na te denken wie je bedankt – en in welke volgorde. Wordt er meer belang gehecht aan de eerste? Of aan de laatste? Of houd je je beter aan de traditionele volgorde? Zal de mate van dank wel uit de vergelijking blijken? Daarom opteer ik voor duidelijkheid:

Dank aan (in willekeurige, doch traditionele volgorde):

- natuurlijk Stef die me na het schrijven van mijn licentiaatthesis vroeg of ik graag schreef. Ik had toen nog geen idee dat dit het begin zou zijn van dit 'boekje'. Ook dank ik je voor de vele aangename jaren binnen de ETE groep en voor de kans om dit uitermate interessante en relevante onderwerp te onderzoeken.

- mijn commissieleden Prof. Bruno De Borger, Prof. Dirk Heremans, Prof. Erik Schokkaert, Prof. Erik Verhoef, die een extra bedanking verdienen voor hun nuttige op- en aanmerkingen en omdat zij met de grootste zekerheid het doctoraat ook echt gelezen hebben. Ik dank hen echter niet voor de (terechte, maar zeer tijdsintensieve) opmerking dat ik beter in alle hoofdstukken dezelfde symbolen gebruik voor snelheid, boete, enzovoort. Ik hoop dan ook dat er geen 'oude' symbolen zijn blijven staan.
- mijn voormalige collega's: Inge en Sandra voor de broodnodige koffiepauzes en de hulp wanneer ik – weer maar eens – ergens (met een idee, een formule of het gevreesde GAMS) 'vast' zat en niet wist hoe te ontsnappen. Ook de andere (ex) ETE (bond)genoten Ellen, Saskia, Edward, Johan, Guido, Denise, Bert W., Fay, George, Gerd, Kurt, Edward en Isabelle wil ik bedanken voor de aangename verjaardagstraktaties, de barbecues, de etentjes en de boswandelingen in sneltempo.
- Mijn ex-bureaugenoten: Bert die het het langst heeft volgehouden om samen met mij in één bureau te zitten, maar natuurlijk hebben ook Andrea, Evi, Klaas en Julien het leven op 'de bureau' veel aangenamer gemaakt. Oh ja, ik wil ook de lunch, koffie en leesgroep vrienden nog bedanken (hmm, dit begint een beetje het dankwoord van een Miss Hoppenfee-verkiezing te lijken...). Maar toch nog eentje: natuurlijk mag het economiesecretariaat – in hun wisselende bezetting – niet ontbreken in dit dankwoord.
- de financiële steun van Belspo (en bij uitbreiding dus dank aan alle belastingbetalers) voor het onderzoeksproject 'Economische analyse van verkeersveiligheid: theorie en toepassingen' waardoor ik 4 jaar aan dit doctoraat kon werken.
- natuurlijk (we zijn er bijna) mijn vrienden, die voornamelijk interesse toonden in de receptie, maar ook met teveel zijn om allemaal bij naam te noemen – ik hoop dat ze hiermee kunnen leven. Ook de familie en dan voornamelijk mijn grootouders dank ik voor hun interesse, afleiding en de vraag 'of ik nu nog niet lang genoeg gestudeerd had'.
- Ik mag uiteraard ook mijn ouders niet vergeten voor het schrijven van voorwoorden (behalve dit voorwoord dan), het babysitten en de 'technische' steun. Bovendien was

dit doctoraat - en dit bedoel ik niet alleen in de meest letterlijke zin- er niet geweest zonder hen.

- Maar wat is een dankwoord waard zonder Christophe, Rune en Marit. Christophe die me heel de tijd bleef steunen en een luisterend oor had voor mijn geklaag. Ik heb hem ooit in een dankwoord bedankt voor de (geveinsde) interesse, maar heb moeten beloven dat ik dit deze keer niet ging doen, want hij is/was terdege geïnteresseerd. Rune en Marit dank ik om te slapen wanneer ik aan mijn 'boekje' wou werken, maar ook om hun 'lawaai' en onvoorwaardelijke blijdschap.

Eef, mei 2007

Table of Content

List of Figures

List of Tables

1

A general overview

"Success is the ability to go from one failure to another with no loss of enthusiasm"

(W. Churchill)

Traffic accidents, and hence traffic safety policy, are as old as traffic itself. Even in the 18th century, the Dutch government realised that regulation was needed. The box below shows that people risked a fine of about 13 euro - a huge amount those days - for 'speeding'. The enforcement was guaranteed by awarding half of this amount to the arresting person. The reason for this regulation was that, because of dangerous driving, many children were injured and – as the text states – even died.

Keure (verordening) tegen het hard rijden binnen Amstelland

. ..klachten... dat door het onbesuisd en hard rijden met paarden en rijtuigen langs de straten en wegen in Amstelland...ongelukken zijn komen voor te vallen tot zoverre dat diverse kinderen zijn overreden, gekwetst, ja zelfs daardoor immediaat zijn komen te overlijden. . . . .Daarom zal niemand zich voortaan dienen te verplaatsen te paard, met wagen of enig ander rijtuig *buiten en boven een ordentelijke draf.*

Te hard draven of onbehoorlijk rijden door de dorpen of enige buurten in Amstelland op de verbeurte van *vijfentwintig guldens* zullen de overtreders . . . mogen worden aangehouden tot de gemelde boete van 25 gulden zal zijn voldaan, zullende *de aanhouder of aanbrenger genieten de helft van de gemelde boete.*

Baljuw van Amstelland, 9 december 1723.

But also today the problem of traffic accidents is not resolved. For example, in Belgium 1100 people die every year, about 4 persons each day (European Road Accident Database, 2007). This tragic number is magnified when we consider the corresponding large number of serious and light injuries. However, the argument for traffic safety is not simply an emotional one: road crashes represent a serious economic burden, which is estimated to represent up to 4 per cent of GDP in some countries[1]. Moreover, there is a lot of government intervention in order to improve traffic safety. The government uses regulation and its enforcement (for example, speed limits, vehicle standards), physical measures (for example, roundabouts, speed humps), liability rules, economic instruments (for example, pricing of transport, insurance rating), education and sensitisation.

This dissertation investigates some of these policy instruments, this is, regulation and its enforcement, liability rules, and a kilometre tax in more detail. First, we focus on the enforcement of speeding. We investigate how one should deal with repeated offenders and analyse the influence of lobby groups on the setting of the probability of detection and the fine. Next, the performance of different liability rules is investigated. Then, as instruments interact with each other, the joint use of a speed limit, liability rules and a kilometre tax is considered. Finally, the concluding chapter brings the main findings together and comments on some assumptions made throughout the dissertation.

In the next paragraph I discuss these issues in more detail, referring to the relevant literature. The last paragraph provides some guidance to the reader.

1. RESEARCH TOPICS AND THE LITERATURE

Four main topics can be discerned in this dissertation: firstly, the optimal enforcement of regulation, secondly, the political economy of traffic regulation, thirdly, the role of liability rules and finally, the joint use of instruments. In the following sections, I discuss the relevant literature and the main idea behind the analyses made, concerning these topics.

1.1. Optimal enforcement of repeated offenders

> *"Hang people for parking violations and there will be no parking violations and no hanging"*
>
> Usher, D. (1986)

---

[1] OECD (2002)

Chapter 2 deals with the optimal enforcement of traffic regulation. This is important because regulation is widely used in transport. Think, for example, of speed limits, technical regulation, mandatory seat belts, etc. However, regulation alone is not enough. There is a need for enforcement of regulation. This enforcement consists of two elements: monitoring and punishment.

Monitoring and enforcement issues were largely ignored[2] until the seminal papers by Becker (1968) and Stigler (1970). The authors assumed rational behaviour among criminals, whose gains from the illicit activity has to be countered by some expected punishment. The Becker model has been considerably extended during the last three decades. Polinsky and Shavell (2000) and Cohen (2000) provide very comprehensive overviews. I apply this framework to traffic accidents, and analyse more particularly the enforcement of speed regulation although the same framework could be used for other traffic violations. The focus in this first chapter is on the enforcement of repeated offenders. The literature on repeated offenders found its formal start with Landsberger and Meilijson (1982). They use a dynamic game-theoretic framework to analyse how prior offences should affect the probability of detection, rather than the level of punishment.

This literature, which mostly deals with environmental regulation and tax evasion, prescribes that repeated offenders should be controlled more often. However, in traffic it is difficult to control one particular person more than another. A logical idea, which is also observed in reality, is to make the fines higher for repeated infractions. However, the literature on this is mixed. Rubinstein (1979) assumed that the government only wants to punish deliberate offences and not accidental ones. He then showed that in an infinitely repeated game an equilibrium exists where the government does not punish agents with a ‘reasonable’ criminal record and all agents try to comply. Harrington (1988) found increasing fines, but does not minimize the control costs. Harford and Harrington (1991) therefore argue that a static solution, where all firms are treated alike will often be superior to a state-dependent solution. Polinsky and Rubinfeld (1991) could explain increasing fines by assuming that people receive an acceptable as well as

---

[2] Notable exceptions are the eighteenth contributions on the economic analysis of public law enforcement of Montesquie (1748) and Bentham (1789).

an illicit gain from the criminal activity. In a traffic situation, except maybe for joy riders, this is not the case. The time gained from speeding does contribute to social welfare. In Polinsky and Shavell (1998) agents live for two periods and can commit a crime twice. They show that the following policy might be optimal: Young first-time offenders and old second-time offenders are penalised with the maximum sanction, while old first-time offenders get a lower sanction. Chu, Hu and Huang (2000) consider, like Rubinstein (1979), a legal system that may convict innocent offenders. The government takes this as a social cost into account. Reducing the fine for first-time offenders and increasing it slightly for second-time offenders has no effect on deterrence but reduces the cost of erroneous convictions. The reason is that the probability of repeated erroneous convictions is lower than for first-time mistakes. Burnovsky and Safra (1994) and Emons (2003), on the other hand, argue that the optimal fining scheme is decreasing. In Burnovsky and Safra (1994) agents decide ex ante on the optimal amount of crimes. In Emons (2003) the behaviour of agents can depend on the history. The main intuition behind these decreasing fine schemes is that increasing the fine for the second offence decreases the fine of the first offence since wealth is assumed fixed. At the same time it is more likely to detect the first offence than the second offence since you are only sanctioned for a second time if you were caught the first time.

We start from the idea that there is a positive relationship between previous convictions and the probability of being involved in an accident. Because drivers differ in their skills, risk taking, etc. This makes that drivers differ in their probability to have an accident. This means that, for the same level of speed, the probability of being involved in an accident is higher for an “incapable” driver than for a “capable” driver. The government does not know who the incapable drivers are, but previous speeding violations may act as a “signal” for being an incapable driver. A basic result from the enforcement literature[3] is that the probability of detection and the magnitude of the fine should be such that

---

[3] For an overview of the literature on optimal enforcement we refer to Polinsky and Shavell (2000).

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

This means that the optimal fine is a function of speed and equals the expected accident costs due to speeding, corrected for the probability of detection. For the same speed and same probability of detection, bad drivers have higher expected accident costs, and should therefore be fined more severely. We confront two fine structures, both increasing with speed: a uniform fine and a differentiated fine, which depends on the offence history. We do not look for the optimal structure, but merely compare these two systems. The theoretical analysis is complemented by a numerical illustration for Belgium in which three fine structures and their effect on welfare are compared: the current fine structure, the theoretically optimal uniform fine structure and the theoretically optimal fine structure which depends on the offence history.

1.2. Political economy of traffic regulation

> *"We must first note that economic factors are taken into account in a world in which ignorance, prejudice, and mental confusion, encouraged rather than dispelled by the political organization, exert a strong influence on policy making."*
>
> R.H. Coase (1966)

The third chapter deals with the political economy of traffic regulations. In Europe, there are at present large variations in the magnitude of the fines and the probability of detection. Moreover, in general, the public debate emphasises raising the probability of detection rather than increasing the fines. This diverges with economic theory[4] that prescribes that fines should be set at a very high level and that monitoring, given the costs, should be set as low as possible. This result is reinforced by the knowledge[5] that both theory and empirical research show that fines perform better as a deterrent than the probability of being caught. However, those very high fines are not observed in reality.

We can think of different reasons why enforcement is as it is. Firstly, given the recent debates in Belgium, it is clear that high fines are not a very popular measure.

---

[4] See for example Becker (1968), Polinsky and Shavell (1979) and Shavell (2004)

[5] Anderson et al (2003), Shavell (1987)

Politicians, who want to be re-elected, take this into account in setting their policy. An electoral accountability model can be used to analyse this. This model was developed by Barro (1973) and further discussed in Persson and Tabellini (2000). A second reason may be that there are lobby groups at work. Think for example of the automobile industry, the motorcycle action group, etc. This leads us to use a second type of model, the common agency model, which analyses the influence of lobby groups. Dixit et al (1997) provide a general discussion of the common agency approach with an application to public finance. Aidt (1998) use the model to analyse environmental policy. Persson (1998) constructs a model of local public goods in which the benefits are concentrated for a well-defined group, while the whole society pays for it. A characteristic of a speeding fine is that only people who speed pay it. If fines are high and the probability of being caught low, the costs of speeding mainly falls on the speeders. If the fines are low and the probability of being caught is high, the costs of speeding mainly fall on society as a whole because they pay for the monitoring costs. Recently, Makowsky and Stratmann (2007) study the political economy determinants of traffic fines. They empirically estimate the influence of the incentives faced by police officers and their vote maximizing principals on speeding tickets. Their findings indeed show that the size of the violation is not the sole determinant of the fine and that it is also determined by the policy officers' objective functions.

In chapter 3 we use the model of Dixit et al (1997), assuming two lobby groups – 'strong' road users and vulnerable road users – to analyse the choice of the fine and the inspection probability. We derive three equilibriums by maximising an objective function equal to a weighted sum of a social welfare function and the utility functions of the lobbying groups. In the benchmark case, lobbies have no influence. In the other two extreme cases, first the vulnerable road users are the only effective lobby; secondly, the strong road users get all the weight. If only vulnerable road users are effective in lobbying, we anticipate that the expected fine is higher than if only strong road users are taken into account. When we consider the choice between inspection probability and the magnitude of the fine for a given expected fine, we find that the fine preferred by the vulnerable road users is higher and the inspection probability lower than socially optimal. The reverse holds if only strong road users are the effective lobbyists. The orders of magnitude are illustrated numerically for speeding and contrasted with fines for drunk driving in the European Union.

1.3. *The role of liability rules*

"Safety doesn't happen by accident"

Author Unknown

Liability rules consist of confronting the car drivers with the real costs of their driving and by that, influencing their behaviour. Under liability, you only have to pay the damages if an accident happens; it is an ex post approach. In contrast, fines are paid ex ante, before an accident happens.

There are two main kinds of liability rules. The first one is strict liability. In its simplest form, strict liability dictates that if A damages B then A is liable for that damage. The second kind is the negligence rule. Under negligence, A is only liable for the damage inflicted if A has failed to exercise an 'appropriate' degree of care in carrying out his/her business. If A takes less than this due care and causes an accident, A is found liable and has to pay the damage. All other liability rules (for example, comparative negligence, strict liability with contributory negligence, etc.) are based on one of these two.

In Belgium a rule of negligence applies for accident between motorised vehicles. However, for accidents between a motorised vehicle and a vulnerable road user, the driver of the motorised vehicle is strictly liable[6]. The main reason for this distinction was a budgetary matter. Before 1989 a rule of negligence applied for all accidents and the medical costs of the vulnerable road users were mainly paid by the social security system. By making car drivers strictly liable for accidents with vulnerable road users, the medical costs are now shifted to the insurance of the motorised vehicle. Moreover, it was argued that this change of liability rule would not alter the incentives of the vulnerable road users. They would still act carefully because they risk life and limbs. The main goal of this chapter is to investigate whether this is true. How do different liability rules influence the behaviour of road users when explicitly taking into account the risk of being injured?

---

[6] Article 29 bis of Belgian Act of 21 November 1989, Article 1382 of the Belgian Civil Code

There is already an extensive literature on liability rules. Good surveys can be found in Shavell (1987, 2004) and in Cooter and Ulen (2004). However, the theory considers different models of accidents and all these different models lead to different conclusions with respect to the performance of liability rules. The next section discusses the five most important differences between these models.

Firstly, some authors only consider the level of care (for example, Adams 1989, Sloan ea 1994) while most (for example, Shavell 1987, Cooter and Ulen 2004, Boyer and Dionne 1987, Van den Bergh 1998) consider both the level of care and activity. Both care and the activity level influence the expected accident cost. Care is often defined as the acts which can be put into a regulation, such as the level of speed, wearing a seat belt, etc. Activity stands for the acts which are more difficult to control such as looking in the rear mirror, the number trips, etc. Secondly, a distinction is made between unilateral accidents, in which only one party influences the probability of an accident, and bilateral accidents, in which both parties influence the probability of an accident. If accidents are unilateral, strict liability leads to the optimal care and activity level. Negligence will only lead to the optimal care level if the due care level is set optimally. See for example Shavell (1987) for an analysis of the effects if due care is not set optimally. Given that the activity level is not included in the standard of due care, people will not adapt their activity level. If accidents are bilateral, strict liability does not lead to the socially optimal care and activity levels, while negligence leads to the socially optimal care levels but not to the socially optimal activity levels. Thirdly, in some accident models either only one party suffers losses (as in the case of an accident between a cyclist and a car) or both parties have losses (as in a car-car accident). See for example Arlen (1990) for a discussion on accidents in which only one party has losses and Boyer and Dionne (1987) or Landes and Posner (1987) for a discussion on accidents in which both parties have losses. In bilateral accident models in which only one party has losses, all rules involving negligence lead to efficient care by both parties. However, there exists no rule which make that the activity level is optimal for both. If both parties have losses we can again obtain optimal care levels. However the activity level will never be optimal. Fourthly, the losses may be purely pecuniary or also partly non-pecuniary. A pecuniary loss is the loss of a good, which has a substitute on the market. An example of a pecuniary loss is the material damage to the car that is caused by the accident. A non-pecuniary loss can be seen as the loss of unique and irreplaceable commodity. Examples of non-pecuniary losses are death, injury, emotional distress, etc. See for example Shavell (1987, chapter 10), Arlen (1985, 1990, 1992) and Visscher (1998) for a discussion on liability rules if losses are non-pecuniary. Finally, people may be risk neutral or risk averse. If people are risk averse the social optimum involves not only a decrease in accident losses but also protection against risk. In the literature, this is, among others, discussed by Shavell (1987, Chapters 9 and 10), Arlen (1990), Posner (1998) and Van den Bergh (1998) in the setting of a unilateral accident model.

In order to answer the question 'will the cyclist take care simply because he might get hurt, we analyse the performance of different liability rules for accidents between a car and a vulnerable road user. These are accidents in which both (risk-averse) parties influence the probability and both have losses, in which the damages are both pecuniary and non-pecuniary and in which both care and activity play a role. We investigate whether the liability rules are sufficient to reach the socially optimal level of accidents or whether we need to complement them with other instruments such as regulation or economic instruments? And what happens if we introduce insurance?

1.4. *The choice of policy instruments*

> *"A government with several economic targets must have at least as many policy instruments"*
>
> Tinbergen, J., 1956

The selection of a suitable policy instrument mix is one of the hardest decisions in the design of traffic safety regulations. Up to now, the law and economics theory mostly focuses on the separate use of instruments and on how to choose between them. See for example Shavell (1984b) for the choice between liability and regulation and Polinsky and Shavell (2000) for the choice between fines and imprisonment. At most the combination of two instruments is considered, as in Shavell (1984a) and Kolstad et al. (1990), Burrows (1999) and Schmitz (2000) who all consider both liability and regulation. A notable exception is the paper by Boyer and Dionne (1987), which considers regulation, liability, taxes and insurance.

Chapter five deals with the joint use of three imperfect policy instruments: liability rules, regulation and its enforcement and a kilometre tax. It considers two determinants of the accidents cost: speed and the number of kilometres people drive. In the model, drivers maximise their utility of driving with respect to the level of speed and activity, taking into account the costs of driving. If the government does not intervene I assume that all accident costs are external to the driver; he will only take into account his private costs. Hence he will drive too fast and too much. The three instruments (alone or in combination) make that the driver takes into account some of the accident cost. How much depends on the instruments. Given the assumptions about the efficiency of the instruments the social optimum is never obtained. The theory is illustrated for 3 types of roads – urban, interurban, highway and three types of users – business, commuters and others. I calculate the private and social optimal levels of speed and the levels of speed under the different instruments. The welfare losses for the different instruments are computed.

1.5. Some preliminary remarks

> *"Judicious omission is preferable to correct superfluity"*
>
> Kidde, W.

Before turning to the different chapters, I want to point out that these chapters embrace several assumptions. The main reason for this is to keep the analysis clean and to focus on the main message.

First of all, insurances are only taken into account – and even then in a simplified way – in chapter four which deals with liability rules. In all other chapters we only briefly comment on their existence. This is in strong contrast with reality, where liability insurance is mandatory in most European countries. Including insurance issues would require a thorough analysis of their working and this is out of the scope of this dissertation. But the existence of insurance does not influence directly the analyses made in the first two chapters as you cannot insure against illegal acts.

Secondly, most of the analyses assume that only one party has losses. This is not a very strict assumption as it can always been seen as a normalisation.

Thirdly, I assume that people only differ in their value of time. Adding more heterogeneity between people like differences in age, gender, etc. would not change the conclusions. The models would remain the same, although more indices would be required.

Fourthly, we restrict ourselves to a very limited idea of social welfare. The social welfare function only takes into account the private costs of driving and the expected accident costs. Other traffic related problems such as congestion and environmental issues are not taken into account. Equity matters are also not accounted for. However, the analysis could be extended to incorporate these issues but this is left for further research.

Further, all of the chapters focus on the behaviour of drivers and more particularly on their choice of speed (care level in chapter four) and the number of km they drive (activity level in chapter four). The reason for this is that behaviour plays a role in 85% of all accidents (Lonero et al, 1995) and that speed, because of its influence on the severity of an accident, plays a role in all accidents.

Finally, other measures than liability, regulation and a km tax are not considered. Of course technical and infrastructural measures, road design and education and sensitisation also play a role in traffic safety policy. An appropriate economic analysis of such measures could take the form of a cost benefit analysis[7]. Although note that it is hard to analyse the effects of sensitisation and education as their effect is often uncertain and temporary.

---

[7] For example, Delhaye (2002) makes a cost-benefit analysis for replacing signalized junctions by a roundabout.

2. A GUIDE TO THE READER

This dissertation deals with transport safety, and particularly investigates in more detail the working of some instruments that are used to increase safety on roads. I first consider two specific instruments in more detail, i.e. the enforcement of speed regulation and the use of liability rules. Next I consider, both theoretically and numerically, the optimal use of three specific instruments; i.e. a speed limit, strict liability and a kilometre tax. Finally, the conclusions repeat the main findings.

In order to facilitate the reading of this dissertation, an overview of the different chapters is provided in Table 1. 1. For each chapter I give some relevant keywords and indicate which policy instrument(s) is (are) investigated.

Table 1. 1: Overview of the dissertation

	Keywords	Instruments
Chapter 2: The enforcement of speeding: should fines be higher for repeated offenders?	Regulation Enforcement Repeated offenders	Fines Probability of Detection
Chapter 3: A policeman at every corner	Political Economy Lobby groups Enforcement	Fines Probability of Detection
Chapter 4: Will the cyclist take care simply because he might get hurt?	Liability rules Non-pecuniary losses Bike-car accidents	Liability rules: negligence, strict liability, comparative negligence Insurance
Chapter 5: Traffic safety: speed limits, strict liability and a km taxt	Liability Regulation Economic Instruments	Strict liability Speed limit Km tax

2

The Enforcement of Speeding: Should Fines be Higher for Repeated Offenders?

Eef Delhaye

1. INTRODUCTION

Since speed plays an important role in most accidents[8], 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[9]. 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[10] be such that

$$optimal\ fine = \frac{\text{expected damage due to speeding}}{\text{probability of detection}} \qquad (1)$$

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[11].

In reality[12] 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

---

[8] For an overview of the literature on speed and its relationship with traffic accidents we refer to Aarts ea. (2006) and Baruya (1997).

[9] 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.

[10] Polinsky and Shavell (2000).

[11] European Commission (2004).

[12] European Commission (2004)

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[13]. There are, nonetheless, three reasons why it might be desirable to condition fines on the offence history[14].

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. They 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 - which is also observed in reality - to make the fines higher for repeated infractions. However, the literature on this is ambiguous. Rubinstein (1979) assumes that the government only wants to punish deliberate offences and not accidental ones. He then shows that in an infinitely repeated game an equilibrium exists where the government does not punish agents with a ‘reasonable’ criminal record and all agents try to comply. Harrington (1988) has found increasing fines for environmental violations, but 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, shows that for wealth-constrained agents who may commit an act twice, the optimal fines are the offender’s total wealth for the first and zero for the second crime. In other words, he finds that the optimal fining scheme is decreasing. The intuition is that increasing the fine for the second offence lowers the fine for the first offence, since

---

[13] Polinsky and Rubinfeld (1991)

[14] The first two are also stated in Polinsky and Shavell (2000)

wealth is assumed fixed over the two periods. Furthermore, a high probability event, this is the detection of the first offence, is more effective use of scarce money resources than a low probability event, namely a second detected offence. The probability of detecting a second offence is lower than the detection of a first offence since you are only sanctioned for a second offence if and only if you were already sanctioned for a first offence. Emons (2004) finds that, if he allows for accidentally committing the crime, the optimal scheme is decreasing if the benefit of the harm is small and increasing if the benefit is large. He assumes that people choose once whether they will always commit the crime or always try to comply. Hence they cannot change their behaviour depending on the fines they face. Another approach by Polinsky and Shavell (1998) finds that it is optimal to reward good behaviour. The optimal sanction for a first time offence equals the sanction for a repeated offender in the second period while the sanction is lowered in the second period if the offender does not have a record. We cannot apply this model to speeding since there is no record of the people who passed the speeding camera complying.

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 – unobserved - illicit gain from the criminal activity. Repeated offences may then be a signal for high illicit gains. 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. Baik and Kim (2001) extend the model of Polinsky and Rubinfeld (1991) and allow for social learning of illicit gains. They find that if social learning of illicit gains is more important than the inherent characteristic of born offenders, it may be desirable to punish first-time offenders as severely as repeat offenders. This is because potential offenders cannot be successfully deterred unless fines are high enough to offset their expected gains from the social learning. Both papers explicitly assume that these illicit gains should not be taken into account in the social welfare function.

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 without additional costs.

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' or incapable driver than for a 'good' or capable driver. Moreover, even if an incapable driver decides that he wants to comply, there is a probability that he will speed 'by accident'. This makes that incapable 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 incapable drivers are, but previous accidents and speeding violations may act as a 'signal' for being a incapable 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 other things, 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. Given the focus of this chapter we only consider the speed decision and hence implicitly assume that the activity level, this is the number of trips or the number of km, is fixed. 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

The individual driver chooses his speed, for a given trip, by minimizing his private cost $C(s)$, which only depends on the level of speed s. $C(s)$ consists of the sum of the resource cost, the fuel cost and the time cost. We assume that this cost function is convex, $C_{ss} \geq 0$. 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[15]. In the remainder of the text we use ‘car driver’ for the injurer and ‘cyclist’ for the victim. We

---

[15] 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 $C(s)$.

distinguish two types of drivers, capable and incapable ones, which differ in their ability to comply with the regulation and in their expected accident costs. The probability of an accident $p(s,q_i)$ depends on the level of speed, s and on the individual propensity to have an accident q_i. People are either capable, $q_i = g$, or incapable drivers, $q_i = b$. For a given level of speed, the probability of being involved in an accident is higher for incapable drivers than for capable drivers, $p(\tilde{s},b) > p(\tilde{s},g)\ \forall\tilde{s}$. For a given type q_i, the probability of an accident is increasing in the level of speed, $p_s(s,q_i) > 0$ ($p_{ss}(s,q_i) \geq 0$). Note that in reality this does not need to be true for very low speeds, for example when there is congestion. As long as the probability of an accident, even at low speeds, is larger for incapable drivers than for capable drivers this does not alter the results. If an accident happens, the victim incurs harm h. Drivers also differ in their ability to comply with regulation. A capable driver who wants to comply will comply. We assume that incapable drivers who want to comply can still speed unintentionally. If incapable drivers unintentionally speed, they drive at speed $s_b^a = s^o + e, e > 0$[16], where s^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 capable drivers[17]. Hence, incapable drivers make decisions as if they are capable drivers. For example, they do not take into account that they can speed by accident. There are g capable drivers and $(1-g)$ incapable drivers[18]. 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

---

[16] Other papers which use assymetrical errors are, for example, Russel (1990), Nyborg and Telle (2004) and Bose (1995).

[17] 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.

[18] g is exogenously given with $0 < g < 1$. We normalise the population to one.

$$\min_s C(s) \Rightarrow C'(s) = 0 \qquad (2)$$

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

The social optimum[19] on the other hand takes into account the expected accident costs and is determined by

$$\min_s C(s) + p(s,q_i)h \Rightarrow C'(s) = -p_s(s,q_i)h \qquad (3)$$

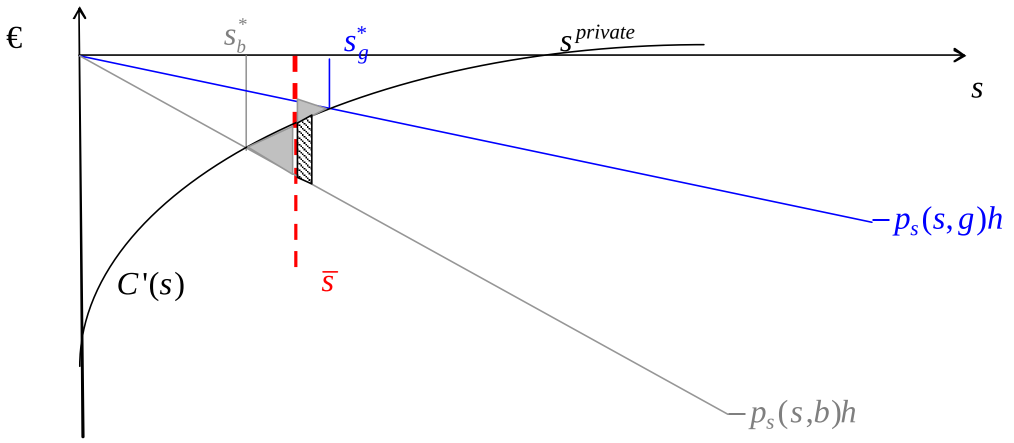
The socially optimal level of speed $s^*_{q_i}$ is determined by the point where the marginal cost of lowering the speed equals the marginal social utility of lowering the speed, which equals the decrease in expected social accident costs. Without government intervention, car drivers do not take the full costs of driving into account and drive too fast. We show this in Figure 2. 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 $C'(s)$. The downward sloping lines are the negative of the marginal accident cost for the capable and the incapable driver, $-p_s(s,q)h$. 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 $s^*_b < s^*_g < s^{private}$. The government can bring the private optimal speed closer to the socially optimal level by the use of different instruments, such as liability rules, infrastructure, vehicle regulation or speed limits. In this paper we focus on the use of a speed limit[20]. The government influences the drivers' choice of speed by setting a speed limit and by the associated enforcement policy. We distinguish two stages: in a first stage the government sets the speed limit, in the second stage it determines the enforcement policy.

---

[19] We do not take into account the environmental and noise costs in determining the socially optimal speed. Rietveld et al. (1998a) calculate the socially optimal speed taking into account the private costs, the accident costs, the environmental costs, etc.

[20] We refer to Delhaye (2006) (Chapter 5) for the influence of regulation, strict liability and/or a km tax on speed.

Figure 2. 1: Private and social optimal level of speed



2.3. *Speed Limit*

We first discuss the setting of the 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 $\overline{s}$. The regulator minimises the expected social costs, shown in equation (4), taking into account the distribution of drivers' types and the probability q with which incapable drivers speed unintentionally.

$$\begin{aligned}
&\min_s\Big(g\big[C(s)+p(s,g)h\big]+(1-g)(1-q)\big[C(s)+p(s,b)h\big]+(1-g)q\big[C(s+e)+p(s+e,b)h\big]\Big)\\
&\Rightarrow\big[g+(1-g)(1-q)\big]C_s(s)+(1-g)qC_s(s+e)=\\
&-g\,p_s(s,g)h-(1-g)(1-q)\,p_s(s,b)h-(1-g)qp_s(s+e,b)h\\
&\Rightarrow C_s(s)=-g\,p_s(s,g)h-(1-g)\,p_s(s,g)h
\end{aligned}\tag{4}$$

This gives $\overline{s}$ the optimal uniform speed limit with $s_b^*\le\overline{s}\le s_g^*$. Given that e is small we asssume that

$$\begin{aligned}
p_s(s,b)&=p_s(s+e,b)\\
C_s(s)&=C_s(s+e)
\end{aligned}\tag{5}$$

If we do not assume (5), the solution of (4) lies on the intersection of a curve strictly below $C_s(s)$ and a curve strictly above or equal to $g\,p_s(s,g)+(1-g)\,p_s(s,b)$ because $C_s(s)$ is strictly concave and $p_s(s,q_i)$ is convex[21]. The 'true' socially optimal speed limit can then be somewhat lower or higher than $\overline{s}$. In Figure 2. 1, $\overline{s}$ is represented by the dotted line. The uniform speed limit makes that incapable drivers drive faster than optimal, while capable drivers drive too slow. The grey areas in Figure 2. 1 represent the welfare losses under perfect compliance compared to the social optimum. For the proportion q of incapable 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 $\overline{s} < s^{private}$, no driver has an incentive to comply and they all drive at their private optimal speed. Therefore we need to discuss the enforcement strategy.

2.4. *Enforcement*

The government uses a fine $j(s)$ and a probability of detection p 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 function. 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

$$j(s) \text{ with } \begin{cases} j(s) = 0 \text{ for } s \le \overline{s} \\ j(s) > 0 \text{ for } s > \overline{s} \end{cases} \tag{6}$$

---

[21] For reasons of clarity we assume for the figures that $p_s(s,q_i)$ can be represented by a straight line. This assumption does not influence the results.

The government determines the uniform fine[22] by setting the private cost of driving at a chosen speed $s > \bar{s}$ equal to the expected social cost of driving at speed $s > \bar{s}$. Using assumption (5) again, we find that

$$\begin{aligned} &\left[g+(1-g)(1-q)\right]C_s(s)+(1-g)qC_s(s+e)+pj(s)= \\ &\left[g+(1-g)(1-q)\right]C_s(s)+(1-g)qC_s(s+e)+E\left[p(s,q_i)h\right] \\ &\Rightarrow pj(s)=g\,p(s,g)h+(1-g)(1-q)p(s,b)h+(1-g)qp(s+e,b)h \\ &\Rightarrow j^{*}(s)=\frac{g\,p(s,g)h+(1-g)(1-q)p(s,b)h+(1-g)qp(s+e,b)h}{p} \end{aligned} \tag{7}$$

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 choose to drive at the speed limit and $j(s)=0$. He will not drive slower than the speed limit because $\bar{s} < s^{private}$. If he speeds, the problem for the driver becomes,

$$\min_{s} C(s)+dj(s) \Rightarrow C_s(s)=-pj^{*}{}'(s) \tag{8}$$

This fine encourages the driver to drive[23] at the speed limit $\bar{s}$. However, q percent of the incapable drivers will speed by accident and drive at speed $s_b^a=\bar{s}+e,\ e>0$. Given that all drivers think that they are capable drivers, they will not take this into account when choosing their level of speed.

We show this in Figure 2. 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 cost of speed, which is the expected fine. This happens at $\bar{s}$. Hence capable drivers drive slower than socially optimal and incapable drivers drive faster $\left[s_b^{*} \le \bar{s} \le s_g^{*}\right]$. q percent of the incapable

---

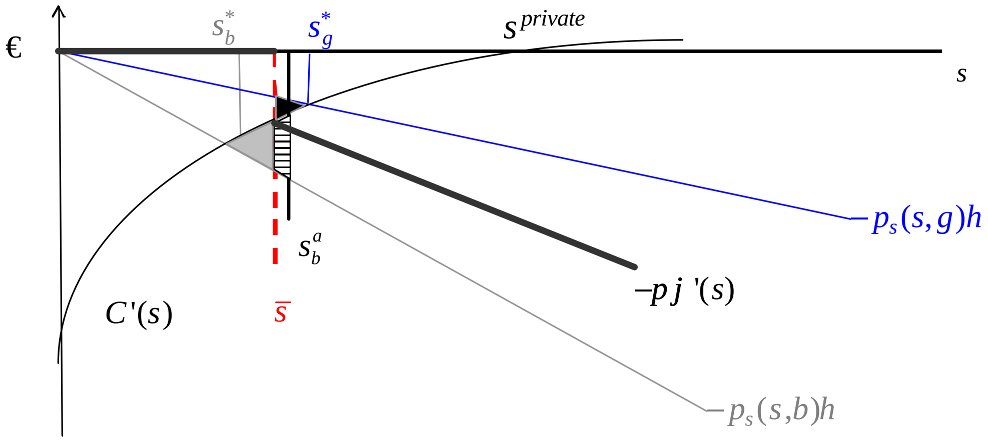
[22] Note that any expected fine larger than the gain of speeding $\left[C(\bar{s})-C(s)\right]$ and positive for speeds higher than the speed limit $[s>\bar{s}]$ makes that drivers want to comply. The exact magnitude of the uniform fine does not influence our analysis given that it does not influence q nor the activity level. Following the traditional enforcement literature, we opt to set the fine equal to the expected cost of speeding.

[23] Insert (7) in (8), assume (5) and compare with (4)

drivers will drive at speed $s_b^a > \bar{s}$. The social welfare loss for a capable driver $\left(WL_g\right)$ equals the black triangle in Figure 2. 2. They have to drive at a speed where the marginal benefit of increasing ones' speed – the private cost- is higher than the marginal social costs – the accident costs. The grey triangle represents the social welfare loss for a incapable driver who complies $\left(WL_b\right)$. They drive at a speed where the marginal benefit of speed is lower than the marginal social costs. The welfare loss for a incapable driver who fails to comply equals the grey triangle, $\left(WL_b\right)$, plus the hatched trapezium, $\left(WL_b^a\right)$. Total social welfare loss of a uniform fine $\left(WL_{uf}\right)$ then equals

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

Figure 2. 2: Uniform fine



(b). Fine depends on offence history

The government does not know who the capable and the incapable 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. The model does not change if we assume that only accidents or only speeding is recorded. However, since accidents are a rare event, accidents on their own will probably not provide enough information to distinguish between both groups. Similarly, not all speeding is recorded and the occurrence of accidents may give additional information about the drivers' type if the probability of having an accident for incapable drivers is distinguishably larger than for capable drivers. If not, including accidents on the record only creates noise.

Both groups will consist of capable and incapable drivers. This is an important difference with the uniform case. Denote P_{nr}^{g} as the proportion of capable drivers without a record, P_{r}^{g} the proportion of capable drivers with a record, P_{nr}^{b} the proportion of incapable drivers without a record and P_{r}^{b} the proportion of incapable drivers with a record. Note that $P_{nr}^{g}+P_{r}^{g}=1$ and $P_{nr}^{b}+P_{r}^{b}=1$. We calculate these proportions in equilibrium using Markov chains later in this paper.

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

$$j(s,k) \text{ with } \begin{cases} j(s,k)=0 \text{ for } s \leq \overline{s} \\ j(s,k)>0 \text{ for s} > \overline{s} \end{cases} \tag{9}$$

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 capable driver and equates the private costs with the social costs for a capable driver. This means that

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

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

$$\begin{aligned} &C(s)+pj(s,1)=C(s)+p(s,b)h \\ &\Rightarrow j^{\circ}(s,1)=\frac{(1-q)p(s,b)h+qp(s+e,b)h}{p} \end{aligned} \tag{12}$$

We admit that this fine structure is a rather arbitrary decision. However, setting the fine for people without a record equal to the expected accident costs of a good driver makes that good drivers drive at their socially optimal speed. Hence the behaviour of this group creates no welfare losses as long as they are not caught. In fact, increasing fines may be preferred over uniform fines, not because they punish incapable drivers more harshly, but because they allow good drivers to drive faster than the speed limit, which is set too low for them. The fine for people with a record must be set higher than the fine for a first-time offence such that these people choose to comply. We choose this structure because it makes that incapable drivers pay for the expected accident costs they create when they speed unintentionally.

Hence, we do not assume that the regulator sets the fines socially optimal. Comparing (12), (10) and (7) yields immediately that $j^{\circ}(s,1) \geq j^{*}(s) \geq j^{\circ}(s,0)$. 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 $\bar{s} < s^{private}$ and they will not pay a fine. Remember that incapable drivers can speed unintentionally with probability q. If they do speed[24], they pay a fine, which depends on their criminal record. There are four cases we need to consider: capable drivers with and without a record and incapable drivers with and without a record.

This approach either implicitly assumes that drivers are myopic or if they are forward looking it assumes that we are dealing with "average compliance cost" - drivers. For Harrington (1988) shows in a model where firms differ with respect to their compliance costs, that confronted with an enforcement strategy which takes into account past compliance, firms have four strategies: either they comply or they violate all the time whether they have a record or not, or they comply when they have no record and violate when they have a record, or they violate when they have no record and comply if they are in the record group. He then shows that the third strategy (comply when no record– violate when record) is always dominated; that low cost firms/people always comply and high cost firms always violate[25]. The most interesting group – which is also the group that we discuss – are the firms (in our case drivers) with average compliance

---

[24] You cannot comply by accident.

[25] This coincides with our findings in chapter 3 and chapter 5 where we find that people with a low value of time comply and people with a high value speed. In this chapter we concentrate on the differences in capabilities and did not differentiate with respect to the value of time.

costs and they choose to violate when they have no record and to comply when they have a record.

We first discuss, with the help of Figure 2. 3, the case for drivers without a record and then turn, using Figure 2. 4, to the case where drivers have a record. Both figures have the same structure as Figure 2. 1. For $s \leq \bar{s}$, $j(s,k)$ equals zero and coincides with the horizontal axis. For $s > \bar{s}$, $j(s,0)$ is given by the fat line in Figure 2. 3 and coincides with the marginal accident cost for the capable drivers. $j(s,1)$ coincides with the marginal accident cost for the incapable drivers and is represented by the fat line in Figure 2. 4.

1) Capable drivers with no record.

When capable drivers speed their problem is represented by

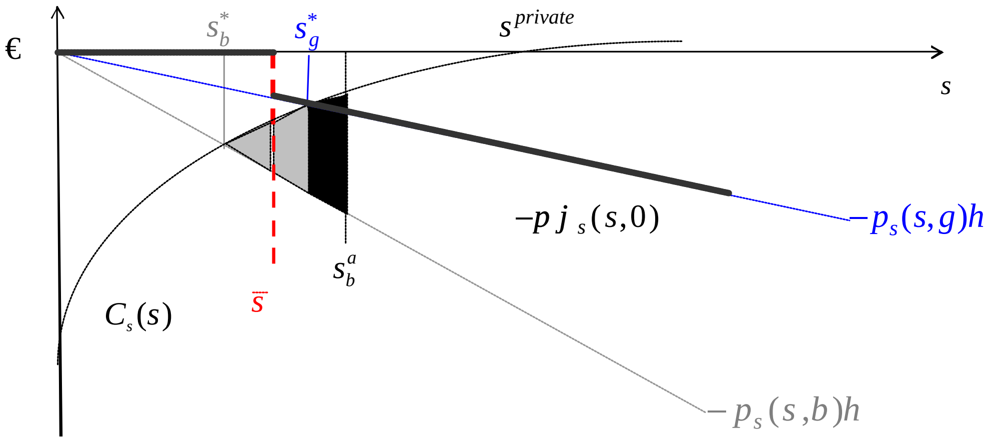
$$\begin{aligned} \min_s C(s)+pj(s,0) &\Rightarrow C_s(s) = -pj_s(s,0) \text{ (using (9))} \\ &\Rightarrow C_s(s) = -p_s(s,g)h \end{aligned} \tag{12}$$

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

2) Incapable drivers with no record

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

Figure 2. 3: Differentiated fine for drivers without a record



3) Capable drivers with a record

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

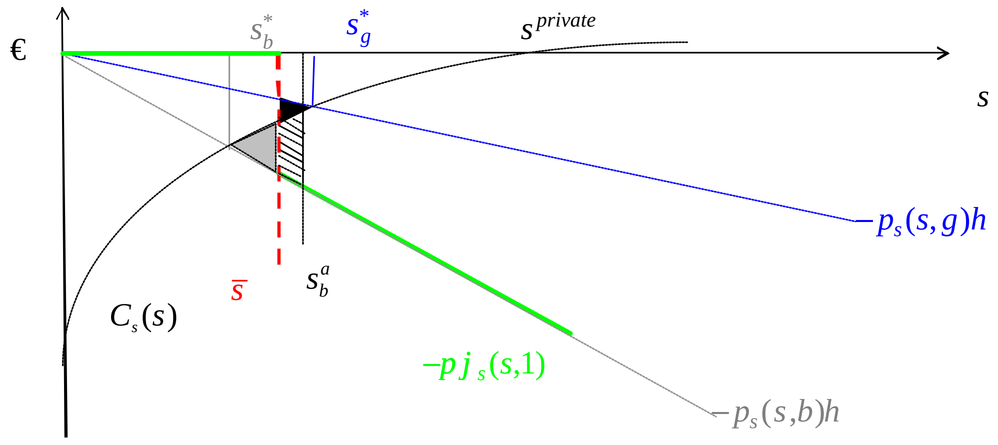
$$\begin{aligned} &\min_s C(s)+pj(s,1) \Rightarrow C_s(s)=-pj_s(s,1) \ \text{(using (10))} \\ &\Rightarrow C_s(s)=-p_s(s,b)h \end{aligned} \tag{13}$$

Mathematically they choose speed $s_b^* < \bar{s}$. However, at this speed the expected fine is zero. Hence they will drive faster than s_b^* until they right hand side becomes positive. This is, they will choose to drive at the maximum speed limit. The welfare loss for this group (WL_g^r) equals the black triangle in Figure 2. 4.

4) Incapable drivers with a record

Incapable drivers with a previous record also face problem (13); hence they try to comply. A proportion $(1-q)$ of incapable drivers drive at the maximum speed level and their welfare losses (WL_b^r) are denoted by the grey triangle. The other q percent of incapable drivers speed unintentionally and their welfare losses equal the grey triangle, (WL_b^r) and the small hatched trapezium, (WL_b^{ra}) in Figure 2. 4.

Figure 2. 4: Differentiated fine for drivers with a record



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

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

(c). Comparison of welfare losses.

Which structure of fines should the regulator choose? He has to 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 preferable if the welfare losses are lower than under a uniform fine, this is, if

$$\begin{aligned}
&0+(1-g)P_b^{nr}\left(WL_b^{nr}+qWL_b^{nra}\right)+gP_g^r\underbrace{WL_g^r}_{=WL_g}+(1-g)P_b^r\left(\underbrace{WL_b^r+qWL_b^{ra}}_{=WL_b+qWL_b^a}\right)\\
&<gWL_g+(1-g)\left(WL_b+qWL_b^a\right) \qquad (15)\\
&\Rightarrow (1-g)P_b^{nr}\left(WL_b^{nr}+qWL_b^{nra}\right)<g\left(1-P_g^r\right)WL_g+(1-g)\left(1-P_b^r\right)\left(WL_b+qWL_b^a\right)\\
&\Rightarrow (1-g)P_b^{nr}\left(WL_b^{nr}-WL_b+q\left(WL_b^{nra}-WL_b^a\right)\right)<gP_g^{nr}WL_g
\end{aligned}$$

We cannot say that one structure always dominates the other. In order to be able to compare the welfare losses, we have to calculate $P_{q_i}^r$ and $P_{q_i}^{nr}$. If past violations are a good predictor of the drivers' type - P_b^{nr} very low and P_g^{nr} very high - it is more likely that (15) will hold. We can calculate $P_{q_i}^r$ and $P_{q_i}^{nr}$ in equilibrium, if we know the movements from the drivers in and out the two groups. We argue that capable drivers with no records will speed and move to the ‘record group’ for two reasons: they are caught with probability p or they cause an accident with probability $p\left(s_g^*, g\right)$. Capable 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. Incapable drivers with no record will also speed and have the same probability p of being caught and transferred to the ‘record group’. The probability that they have an accident[26], $p\left(s_g^*, b\right) > p\left(s_g^*, g\right)$ is higher. Hence the probability that an ‘incapable driver without a record’ receives a record is higher than that probability for a ‘capable driver without a record’. If incapable drivers have a record, they will try to comply. However, with probability q they will speed unintentionally and with probability p 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 $u - qp - p\left(\bar{s}, b\right)$. We summarise these movements in the transition matrices represented in Table 2. 1.

Table 2. 1: Transition matrices

Capable drivers			Incapable drivers		
	No record	Record		No record	Record
No record	$1-p-p\left(s_g^*, g\right)$	$p+p\left(s_g^*, g\right)$	No record	$1-p-p\left(s_g^*, b\right)$	$p+p\left(s_g^*, b\right)$
Record	$u-p\left(\bar{s}, g\right)$	$1-u+p\left(\bar{s}, g\right)$	Record	$u-qp-p\left(\bar{s}, b\right)$	$1-u+pq+p\left(\bar{s}, b\right)$

---

[26] It is more correct to replace $p(s,b)$ in the formulas by $(1-q)p(s,b)+qp(s+e,b)$. We choose not to do this for the ease of notation. For the numerical example we use the correct formulas

The long run equilibrium, or steady state, probabilities $P_g^{nr}, P_g^{r}, P_b^{nr}$ and P_b^{r} may be found[27] by solving the following sets of linear equations:

$$\begin{aligned} &\Pi_g^{nr} + \Pi_g^{r} = 1 \\ &\Pi_g^{nr} = \left(1 - p - p\left(s^*, g\right)\right)\Pi_g^{nr} + \left(u - p\left(\bar{s}, g\right)\right)\Pi_g^{r} \end{aligned} \tag{16}$$

And

$$\begin{aligned} &\Pi_b^{nr} + \Pi_b^{r} = 1 \\ &\Pi_b^{nr} = \left(1 - p - p\left(s^*, b\right)\right)\Pi_b^{nr} + \left(u - qp - p\left(\bar{s}, b\right)\right)\Pi_b^{r} \end{aligned} \tag{18}$$

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

$$\begin{aligned} &P_g^{nr} = \frac{u - p\left(\bar{s}, g\right)}{p + u + p\left(s_g^*, g\right) - p\left(\bar{s}, g\right)}, \quad P_g^{r} = \frac{p + p\left(s_g^*, g\right)}{p + u + p\left(s_g^*, g\right) - p\left(\bar{s}, g\right)} \\ &P_b^{nr} = \frac{u - qp - p\left(\bar{s}, b\right)}{p - qp + u + p\left(s_g^*, b\right) - p\left(\bar{s}, b\right)}, \quad P_b^{r} = \frac{p + p\left(s_g^*, b\right)}{p - qp + u + p\left(s_g^*, b\right) - p\left(\bar{s}, b\right)} \end{aligned} \tag{17}$$

In general $P_g^{nr} > P_b^{nr}$ and $P_g^{r} < P_b^{r}$, so proportional to the population, it is most likely that there are more capable drivers than incapable drivers in the 'no record group' and that there are more incapable than capable drivers in the 'record group'. Note that mathematically it is possible that $P_b^{nr} < 0$ and $P_b^{r} > 1$, but we restrict all proportions to $[0,1]$.

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 first sight, it is still impossible to see which structure will perform the best. It depends mainly on the level of g, $\Pi_{q_i}^{\mathrm{nr}}$ and $\Pi_{q_i}^{\mathrm{r}}$. However, for one, although unrealistic, case the situation is clear-cut. If the probability

---

[27] In general, the steady state probability Π_j may be found by solving the following set of equations (Winston, 1994): with t_{kj} the kj th element of the transition matrix

$$\begin{cases} P_j = \sum_{k=1}^{k=s} P_k t_{kj} & \left(j = 1,2,...s;\ \textit{omit one of these equations}\right) \\ P_1 + P_2 + .. + P_s = 1 \end{cases}$$

of detection, the probability of speeding unintentionally and the probability of having your record cleared all equal one, $p = q = u = 1$, then $P_g^{nr} = P_g^{r} \approx 1/2$ and $P_b^{nr} \approx 0, P_b^{r} \approx 1$. This is, the incapable group coincides almost perfectly with the record group and the capable drivers are almost evenly distributed into the two groups[28]. In this case, the differentiated fine outperforms the uniform fine for any g. The welfare losses for the incapable drivers are the same under both fine systems, but under the differentiated fine, half of the capable drivers will drive at their socially optimal speed. As already noted, a reason to have increasing fines is that a uniform fine system overdeters good drivers.

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

3. NUMERICAL EXAMPLE

We apply the 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 calculating 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[29]. 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. 2.

---

[28] If you do not get a record after an accidents, we can replace ‘ $\approx$ ’ by ‘=’

[29] De Borger and Proost (1997)

Table 2. 2: Fuel costs

Fuel type	Fuel price (€/l)	Consumption (l/km)	% share
Diesel	0.811	$0.13778 - 0.00242s + 0.000016s^2$	40.6
Gasoline	1.068	$0.0396 + 0.00064s$	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[30]. The sum of the resource cost, the weighted fuel cost and the time cost make that we can express the private costs as

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

The private optimum for drivers then equals 98 km/h (min $C(s)$).

In order to derive the expected accident cost $\left[p(s,q_i)h\right]$ we first consider the present accident risk $(accrisk(a))$, given a current speed of 80 km/h[31], and correct this for changes in speed[32]. We then multiply this risk with the value for the harm done ($h(a)$) with a the accident type. 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 capable driver can then be expressed as .

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

---

[30] Own calculation based on Gunn et al. (1999) and Huber and Toint (2002).

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

[32] Elvik et al (2000) give a formula for calculating the effect of a change in speed on the number of accidents:

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

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

We assume that the accident risk for incapable drivers is 1.59 times[33] the accident costs for capable drivers, this is, $p(s,b)h = 1.59\,p(s,g)h$. Table 2. 3 gives the current accident risk and the cost of an accident.

Table 2. 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 $s_g^* = 71$ km/h and $s_b^* = 64$ km/h.

Given this information and assuming that 20% of the population are incapable drivers and that e =5 km/h, we first calculate the socially optimal uniform speed limit and find that $\overline{s} = 68{,}8$ km/h[34]. Note that this is close to the current 70 km/h speed limit. Next, we calculate the uniform and the differentiated fines, 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 2. 4 shows the results.

---

[33] Stradling et al. (2000)

[34] Note that if no one speeds by accident, $q = 0$, the optimal speed limit increases and equals 69,2 km/h. The reason is that the gain in private costs due to unintentionally speeding is lower than the increased expected accident cost.

Table 2. 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	51	44	78
10-40 km/h	128	89	79	136
+ 40 km/h	court	256	226	381

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

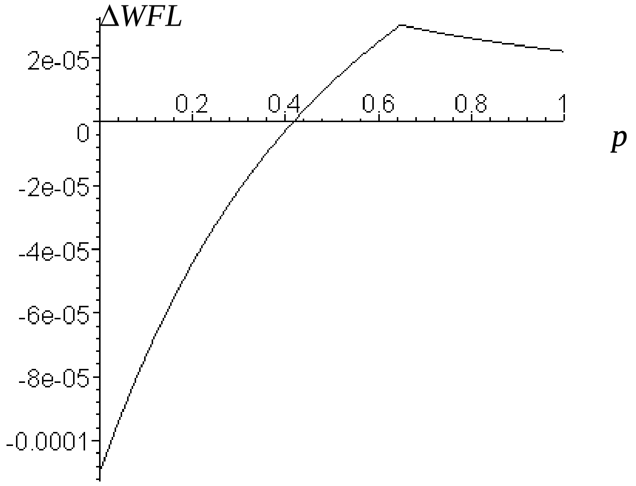
If we assume[35] a probability of detection of 0.9%, the calculated fines for small offences equal the existing ones. For larger offences, the current fines increase more steeply in the level of violation than the calculated fines.

In order to compare these two fining systems, we need to calculate the welfare losses. We let the probability of detection p free. We first assume that 80 % of the drivers are capable drivers ($g = 0.8$), that the probability that incapable 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 'no 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 $P_{q_i}^{r}, P_{q_i}^{nr}$ and the difference in social welfare, ΔWFL (welfare losses uniform fine minus welfare losses differentiated fine). The result is given in Figure 2. 5. Notice that the kink is due to the fact that we imposed that $P_{q_i}^{r}, P_{q_i}^{nr} \in [0,1]$

---

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

Figure 2. 5: Difference in welfare losses if $g = 0.8$, $q = 0.4$, $u = 0.3$, $e = 5$

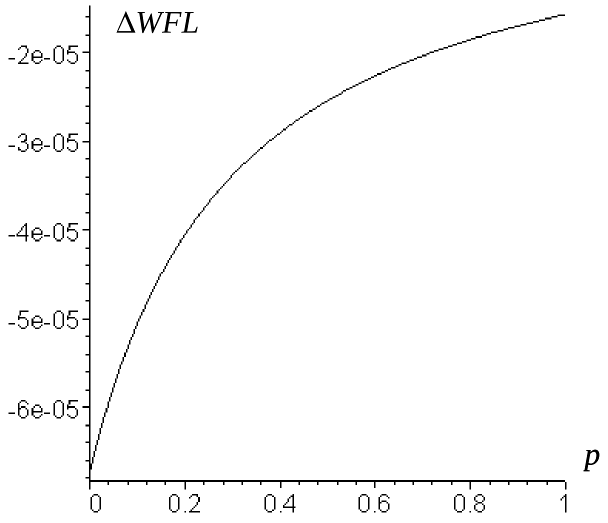


The optimal structure switches for a certain probability of detection. We see that for p <0.417 the uniform fine performs better than the differentiated fine. If p >0.417 the differentiated fine performs better. It is hard to know the real probability of detection in Belgium, but it is most likely lower than 41,7% per trip[36]. In this case we should prefer a uniform fine. The reason for this is that the signal is not strong enough. For example, if we set $q = 1$, this is all incapable drivers speed unintentionally, the differentiated fine is preferred as soon as p >0.179. Moreover, if $q = 1$ and the expected accident cost of incapable drivers is four times the cost of capable drivers, the differentiated fine should be chosen once p >0.12. This is, if the signalling is better, the differentiated fine performs better. When the probability of an accident is the same for both types and hence the only difference is the unintentionally speeding $(q = 0.4)$, the differentiated fine is chosen when p >0.44. Also, when $q = 0$, this is when there is no speeding by accident and the only signalling is the higher probability of an accident for the incapable drivers, a uniform fine is always preferred. We show this in Figure 2. 6.

---

[36] 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.

Figure 2. 6: Difference in welfare losses if $g = 0.8$, $q = 0$, $u = 0.3, e = 5$



As p increases, the differentiated fine performs better. The reason for this is that, if the probability of detection increases, the proportion of incapable drivers with a record also rises and this rise is larger than the rise in capable drivers with a record.

If the probability of clearing the record rises to 80 percent $(u = 0.8)$, the uniform fine always outperforms the differentiated fine. If the probability of clearing the record decreases to 10 percent $(u = 0.1)$, the differentiated fine is preferred once the probability of detection is larger than 7%. Hence, for a given q, the probability of detection under which the differentiated fine performs better decreases in the probability of clearing the record.

If we assume that there are more capable drivers ($g = 0.95$), we find that the differentiated fine performs better if the probability of detection is larger than 0.38. The reason for this is that for a large part of the population the welfare losses will be zero. If g rises, the right hand side of equation (15) becomes larger, while the left hand side becomes smaller, making it more likely that the condition is fulfilled. If there are less capable drivers $(g < 2\%)$, we find that a uniform fine is preferred. For the two corner solutions $(g = 0/1)$ the uniform fine structure is the only solution.

The exercise is not very sensitive for different values of e. If e =1 km/h we prefer uniform fines as long as p <0.42. If e =10 km/h the switching probability of detection equals 0.40. This is, the probability of detection for which differentiated fines become socially a better option increases in e. However, given the interpretation of unintentionally speeding, e cannot grow very large.

This numerical example shows that for reasonable probabilities of detection, the uniform fine should be preferred. The reason for this is that in general the correlation between the type and having a record or not is not very good. Having a record is not a good signal for the drivers' type. Only when incapable drivers drive really bad, this is, they have a high probability of unintentionally speeding and their accident costs are much higher, the differentiated fines are preferred at relatively low probabilities of detection.

4. CONCLUSION

When one analyses existing 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.

We focus on the structure of the fines and on repeated offences. We do not look for the optimal structure, but merely compare two 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 capable and incapable drivers and incapable drivers can speed unintentionally even if they want to comply. Moreover, the expected accident cost for incapable drivers is higher than for capable drivers. Standard theory then prescribes that incapable drivers should be fined more severely than capable drivers. In addition, increasing fines may be preferred over uniform fines because they allow good drivers to drive faster than the speed limit, which is set too low for them. However, the government does not know who is a capable and who is an incapable driver. The literature shows that there is a relationship between the probability of being involved in an accident and the number of previous offences. Hence, we claim that a record of offences may act as a signal for the type of the driver.

A uniform fine makes that capable drivers are fined too harshly and incapable 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 incapable drivers in the ‘no record group’ and capable 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.

The numerical illustration considers two items. 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. Secondly, 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 uniform fine should be preferred. If the signalling function would improve – for example, by including all traffic offences – or if the probability of detection rises, increasing fines would be favoured.

There are three important extensions, which can be made to the model. Firstly, it would be interesting to calculate the socially optimal increasing fine structure. However, this cannot be done within this framework as it stands. Secondly, it would be realistic that people can learn their type. Incapable drivers with a record want to comply, hence if they are caught speeding, they should conclude that they are incapable drivers. Intuitively we can say that including this learning effect makes that incapable drivers drive slower under both fine structures. Hence this will not change the comparison between the two fine structures qualitatively. Thirdly, the role of insurances should be taken into account as they also adjust the premiums according to the history of the driver. If we assume that insurances can perfectly differentiate, the premiums will be higher for incapable drivers and there might be less reason to have (increasing) fines. However, in Belgium, insurance companies only take accident data into account, and not traffic offences. As accidents are still a rare event, insurances will not be able to differentiate and hence (increasing) fines may still be needed.

3

Catching or Fining Speeders: A Political Economy Approach

Eef Delhaye, Sandra Rousseau and Stef Proost

1. INTRODUCTION

In order to increase road safety, there are different monitoring and enforcement strategies to put speed limitations into effect. In general, the public debate emphasises raising the probability of detecting speed violations rather than increasing the fines. In Europe, we see at present large variations in the magnitude of fines[37] and in the probability of detection. Think for example of the variation in enforcement strategies to deter drunk driving in the European Union, which is shown in the final section.

This observation conflicts with basic economic insight that leads to fines set at the highest possible level and minimal (costly) monitoring efforts (Becker (1968)). The traditional law and economics literature already explored different reasons under which this basic insight does not hold. One problem of the Becker result is that it leads to uniform fines. This contradicts with marginal deterrence: if the fine for an offence does not increase with its seriousness, there is no incentive for the individual to commit minor offences rather than more serious one. This argument is usually attributed to Stigler (1970), but the notion of marginal deterrence was already remarked upon in some of the earliest writing of enforcement, for example by Bentham (1789). Note that there may also be resistance to very high fines on grounds of fairness. This is the notion that the magnitude of the sanction

---

[37] European Commission (2004)

should be proportional to the gravity and moral quality of the act (Shavell, 2004). Secondly, Polinsky and Shavell (1979) showed that if people are risk averse, lower fines and a higher probability of detection are socially optimal. Furthermore, Malik (1990) showed that the Becker result does not hold if higher fines induce violators to spend additional resources to avoid punishment. For example, if car drivers install radar detectors to avoid speeding tickets. Finally, Polinsky and Shavell (2000) showed that if enforcement is general the probabilities of detecting the violations are linked. Since the optimal expected sanction is increasing in the harm, this means that the fine can only be maximal for the high harm offences. Enforcement is general when several types of violation may be detected by a single enforcement activity, for example, a police officer may notice speeding and not wearing the safety belt.

In this paper we look at the political forces behind the monitoring and enforcement decisions for speeding. We see public policy as the outcome of a political process that is influenced by lobbying efforts of different interest groups. As an example, we mention the debate triggered by the reform of the enforcement of speed violations in Belgium (March 2006). Several interest groups held conflicting views as illustrated by the following (translated) newspaper headlines:

"The auto lobby is too aggressive" according to the Association of Parents of Road Traffic Victims (De Morgen, 29 March 2006)

"Unjust, these excessive fines. They are 'draconic measures'." according to the Flemish Automobile Association (De Morgen, 29 March 2006)

"It is perfectly defendable to limit high fines. On condition that more resources are spend on an efficient enforcement policy." E. Glorieux, Green political party (De Standaard, 31 March 2006)

We can therefore wonder whether interest groups can influence monitoring and enforcement policies. In the model of Dixit et al (1997) several principals (lobbyists) simultaneously try to control the actions of an agent (policy maker) by promising contributions in return for policy favours. Dixit et al (1997) apply the model to income taxation, while Aidt (1998) uses the model to analyse environmental policy. There might also be other reasons why policy makers opt for high monitoring efforts and low fine levels rather than the theoretically optimal high fines and low inspection probabilities. One can, for instance, use a model of voter behaviour like Barro (1973). Recently, Makowsky and Stratmann (2007) study the political economy determinants of traffic fines. They empirically estimate the influence of the incentives faced by police officers and their vote maximizing principals on speeding tickets. Their findings indeed show that the size of the violation is not the sole determinant of the fine and that it is also determined by the police officers' objective functions.

In this paper, we use the common agency model[38] of Dixit et al (1997) to understand the influence of different lobby groups. We only take two categories of individual agents into account: vulnerable road users and strong road users. First, we analyse the preferred expected fine, i.e. the optimal combinations of the inspection frequency and the magnitude of the fine. The socially optimal combinations serve as a benchmark. This benchmark is then compared to two lobbying equilibriums: first, when the vulnerable road users form the only effective lobby group and, secondly, when the strong road users get all the lobbying weight. We argue that vulnerable road users opt for a higher expected fine than is socially optimal because, in our model, they bear all the accident losses. The strong road users, on the other hand, prefer a very low expected fine since they have to pay the fines and see none of the benefits associated with an increase in traffic safety. Next, we determine numerically the optimal combination of the inspection and fine parameters when the expected fine is kept fixed. In that case, we find that vulnerable road users opt for high fines and a low probability of detection, while strong road users prefer a high probability of detection and low fines. The main explanation for these findings is that increasing the inspection probability is costly for society as a whole, while increasing the fine has no social costs and only affects the car drivers that violate the speed limit.

Our contribution to the existing literature is twofold. First, we use lobby groups to understand the level of the expected fine as well as the choice between the inspection probability and the level of the fine. Second, we incorporate imperfect compliance into the lobbying model.

Section two presents the theoretical model. Section three presents a numerical illustration of the factors at work. Section four concludes.

---

[38] This model of interest groups' influence is based on the common agency model of Bernheim and Winston (1986). Grossman and Helpman (2001) provide an excellent introduction to the theoretical literature on interest group politics.

2. MODEL

The model under consideration focuses on the level of the expected fine and the trade-off between higher fines and a higher probability of detection, but it can also be used to analyse other safety policy options such as road safety investments. We examine different combinations of inspection frequency and fines and use the political weight of different interest groups to explain the variations in the monitoring and enforcement policy that are selected by the policy makers.

2.1. Assumptions

We assume that there are three economic agents:

Vulnerable road users (v): children, pedestrians, bicyclists. These individuals are homogenous and have an identical value of time.

Strong road users (c): car or truck drivers who prefer higher speeds to lower ones. They differ with respect to their valuation of time and are therefore heterogeneous.

The government, who can take the revenue of the fines, cost of enforcement, social costs of accidents and private cost of driving into account.

The total population N consists of N_v vulnerable road users and N_c car drivers with $N = N_v + N_c$. We assume that car drivers are risk averse in their income. Polinsky and Shavell (1979) discuss the impact of risk aversion on the trade-off between the probability and the level of the fine[39]. Contrary to Becker (1968), the optimal fine level is shown to be lower than the maximal fine in the presence of risk averse individuals and measurement errors.

Car drivers are subject to an exogenously given[40] speed limit $\overline{s}$. They drive at speed s such that their utility is maximised. If drivers exceed the speed limit, they are caught with probability p. This probability of detection does not depend on the probability of having an

---

[39] Bar-Ilan (2000) has also considered the risk attitude of road users in order to analyse the behaviour of red light runners. Red light runners are shown to be risk lovers and this explains why they are not deterred by the high expected damages (injuries or even death) combined with the low probabilities of having these damages.

[40] Graves et al (1989) model the policy choice between speed limits and the probability of detection. They show that raising the level of policing is likely to have a lower social cost, at the margin, than lowering the speed limits.

accident[41] nor on the magnitude of the violation. As a case in point, speed cameras are not more likely to film a driver at 120 km/h than one driving at 100 km/h. The costs of enforcement consist of a fixed enforcement cost C_E^F (for example, the cost of a speed camera) and a variable enforcement cost C_E^V (for example, the administrative cost of writing a notice of violation). The total enforcement cost is thus an increasing and convex function of the probability of detection and the number of violators.

Once violators are caught, they face a fine $j\left(s\right) = ff + vf\left(s - \overline{s}\right)$ with ff the fixed fine, vf the variable fine and $\begin{cases} j\left(s\right) = 0 \text{ } if\, s \leq \overline{s} \\ j\left(s\right) > 0 \text{ } if\, s > \overline{s} \end{cases}$. This fine is increasing with the seriousness of the infraction and linear[42]: $j'\left(s\right) > 0$ and $j''\left(s\right) = 0$.

2.2. *Modelling agents' behaviour*

In this section we discuss the behaviour of the three economic agents: vulnerable and strong road users, who are utility maximisers; and the government, which maximises an objective function for which we do not specify the origin. We model, using backward induction, the road users' reaction to the selected monitoring and enforcement policy. Next, we determine the government's preferred monitoring and enforcement strategy for a given level of lobbying activity and the previously determined reaction functions of the road users.

(a). Vulnerable road user

We assume that the utility of the vulnerable road users U_v is quasi-linear and determined by the consumption of other goods, x_v (price normalised to 1), the number of trips taken, $\overline{ac}_v$ (fixed per individual) and the expected accident costs, $p\left(s\right)h$, with $p\left(s\right)$ the probability per

---

[41] It would be more correct to use $\tilde{p} \equiv (1 - p(s))[p] + p(s) = [p + p(s)(1-p)]$ instead of p. $\tilde{p}$ means that with probability $(1 - p(s))$ the car driver is not involved in an accident; then he has probability p that he has to pay a fine if he speeds; with probability p(s) he has an accident and if he then speeded, the probability of a fine equals one. If a person does not speed, $p = \tilde{p} = 0$

[42] In practice, for example in Belgium, linear fines are often used for speed violation because they are easy to communicate and to implement.

trip of having an accident and h the harm caused by the accident[43]. Note that, even though the harm is independent of speed, the expected harm is not. We can make the harm dependent on speed and not the probability or make both dependent. This will not change the results qualitatively as long as we assume that both the probability and the harm are increasing in the level of speed.

Utility, which is additive in trips and consumption, then equals

$$\begin{aligned} U_v &= x_v + \overline{ac}_v \left[g_v - p(s)h - (1 - p(s))0 \right] \\ &= x_v + \overline{ac}_v \left[g_v - p(s)h \right] \end{aligned} \tag{1}$$

with a constant marginal utility of a trip g_v for a vulnerable road user.

The vulnerable road user maximises his utility with respect to his budget constraint

$$x_v \le Y_v + L \tag{2}$$

The individual's consumption of other goods must be smaller than the sum of the exogenously given income Y_v and the lump sum transfer L[44].

This gives us the expression for the indirect utility

$$V_v = Y_v + L + \overline{ac}_v \left[g_v - p(s)h \right] \tag{3}$$

(b). Strong road user

The strong road users differ in their value of time $t \in [t_1, t_2]$ and will, therefore, not all drive at the same speed. We assume that the value of time is continuously, uniformly distributed with probability density $\frac{1}{t_2 - t_1}$ and cumulative distribution $\frac{t - t_1}{t_2 - t_1}$.

The utility U_c of the strong road users is determined by their consumption of other goods, x_c (price equal to 1), the constant[45] number of trips they take, $\overline{ac}_c$, the constant marginal utility of a trip, g_c, the time cost of making the trip $C_T(t,s)$ (with

---

[43] Assuming that vulnerable road users are risk averse to harm does not change the results qualitatively.

[44] We normalise the cost of taking a trip as a vulnerable road user to zero.

[45] If the number of trips is not constant then it depends also on the value of time. This assumption does not really affect our insights.

$\frac{\partial C_T}{\partial t} > 0, \frac{\partial C_T}{\partial s} < 0, \frac{\partial^2 C_T}{\partial t^2} = 0$ and $\frac{\partial^2 C_T}{\partial s^2} > 0$) and the disutility $R^a\left(j\left(s\right)\right)$ of risking to pay a fine per trip[46]:

$$U_c = x_c + \overline{ac}_c g_c - \overline{ac}_c C_T\left(t,s\right) - \overline{ac}_c p\, R^a\left(j\left(s\right)\right) \qquad (4)$$

In order to implement the model of Dixit et al (1997), a quasi-linear utility function is assumed and the car driver is only risk averse with respect to the fine payments. We assume that the disutility of the fine takes a quadratic form

$$R^a\left(j\left(s\right)\right) = a_c^a j\left(s\right) + \frac{b_c}{2} j\left(s\right)^2 \qquad (5)$$

The car driver maximises his utility with respect to his budget constraint. The private monetary cost of driving $C_M\left(s\right)$ is a function of the speed s the driver selects. The private monetary costs include the resource cost and the fuel cost with $\frac{\partial C_M}{\partial s} \lessgtr 0$ and $\frac{\partial^2 C_M}{\partial s^2} \geq 0$. The budget restriction thus equals[47]:

$$x_c \leq Y_c + L - \left[p j\left(s\right) + C_M\left(s\right)\right]\overline{ac}_c \qquad (6)$$

The car driver's indirect utility then takes the following form:

$$V_c = Y_c + L + \overline{ac}_c\left[g_c - C_T\left(t,s\right) - C_M\left(s\right) - p R\left(j\left(s\right)\right)\right] \qquad (7)$$

With $R\left(j\left(s\right)\right) \equiv j\left(s\right) + R^a\left(j\left(s\right)\right) = \left[1 + a_c^a\right] j\left(s\right) + \frac{b_c}{2} j\left(s\right)^2 = a_c j\left(s\right) + \frac{b_c}{2} j\left(s\right)^2$.

The Arrow-Pratt measure of risk aversion for the fine equals $r = -\frac{V''}{V'}$ and thus

---

[46] We assume that the strong road users do not incur any accident losses. This can be considered as a normalisation since in accidents between strong and vulnerable road users, the losses of the strong road user will be negligible.

[47] In this model we normalise the private accident costs to zero. The results of the analysis will not change qualitatively as long as strong road users do not fully internalise total accident costs. In general, people do not take into account the full accident costs due to, among other things, insurance, judgment proof issues or the underestimation of the probability of being involved in an accident.

$$\frac{\partial V_c}{\partial j\ (s)} = -\overline{ac}_c p \left[a_c + b_c j\ (s) \right]$$

$$\frac{\partial^2 V_c}{\partial j\ (s)^2} = -\overline{ac}_c p b_c$$

Assuming risk aversion, $r = -\frac{b_c}{a_c + b_c j\ (s)} > 0$, imposes two conditions on the parameters a_c and b_c[48]:

$$b_c < 0 \ and \ \frac{a_c}{-b_c} > j\ (s) \tag{8}$$

We also know that, if car drivers are risk averse, they prefer a high probability of detection combined with a lower fine to a lower probability and a higher fine with the same expected value (Rothschild and Stiglitz, 1970 and 1971).

We use a two-stage approach to model the strong road users' individual reaction to the monitoring and enforcement policy adopted by the policy maker. In the first stage, the driver decides whether to comply with the speed limit or not. The decision variable is $z(t)$, which is one if the driver is in violation and zero if he is compliant. In the second stage, the driver decides on the speed s that he will drive.

Using backward induction, we first calculate the level of speed for a given compliance decision. If car drivers comply $\left(z(t)=0\right)$, their private optimal speed s^o is below or equal to the speed limit. An interior solution $\hat{s}$ is defined by

$$\left.\frac{\partial V_c}{\partial s}\right|_{z=0} = \frac{\partial C_T(s,t)}{\partial s} + \frac{\partial C_M(s)}{\partial s} = 0$$

Hence, the private optimal speed $s^o(t)$, given that the driver complies, is given by

$$s^o(t) = \begin{cases} 0 & if\ \hat{s}(t) < 0 \\ \hat{s}(t) & if\ 0 \le \hat{s}(t) \le \overline{s} \\ \overline{s} & if\ \hat{s}(t) > \overline{s} \end{cases} \tag{9}$$

---

[48] We assume that the second condition can be met since, in practice, speed has an upper limit and therefore the possible fine that can be imposed is also limited.

The first order condition for drivers, who decide to ignore the speed limit $\left(z(t)=1\right)$, determines $\hat{\hat{s}}$:

$$\left.\frac{\partial V_c}{\partial s}\right|_{z=1} = \overline{ac}_c\left[-\frac{\partial C_T(s,t)}{\partial s} - \frac{\partial C_M(s)}{\partial s} - p\,\frac{\partial R\left(j\,(s)\right)}{\partial s}\right]$$
$$\Rightarrow \frac{\partial C_T(s,t)}{\partial s} + \frac{\partial C_M(s)}{\partial s} = -p\,\frac{\partial R\left(j\,(s)\right)}{\partial s} \qquad (10)$$

The private optimal speed $s^{oo}\left(\equiv s^{oo}(t,p,j) = max\left[\hat{\hat{s}},\overline{s}\right]\right)$ is determined by equating the marginal benefit to the marginal cost of driving faster. The marginal benefit is the reduction in private costs of driving one km/h faster. The marginal cost represents the disutility of the expected change in the fine due to the increase in speed.

Using these results, we now turn to the driver's compliance decision. A driver speeds if the following condition is met:

$$z(t) = 1 \text{ if } D > 0 \text{ with } D = V_c\big|_{z=1} - V_c\big|_{z=0} \qquad (11)$$

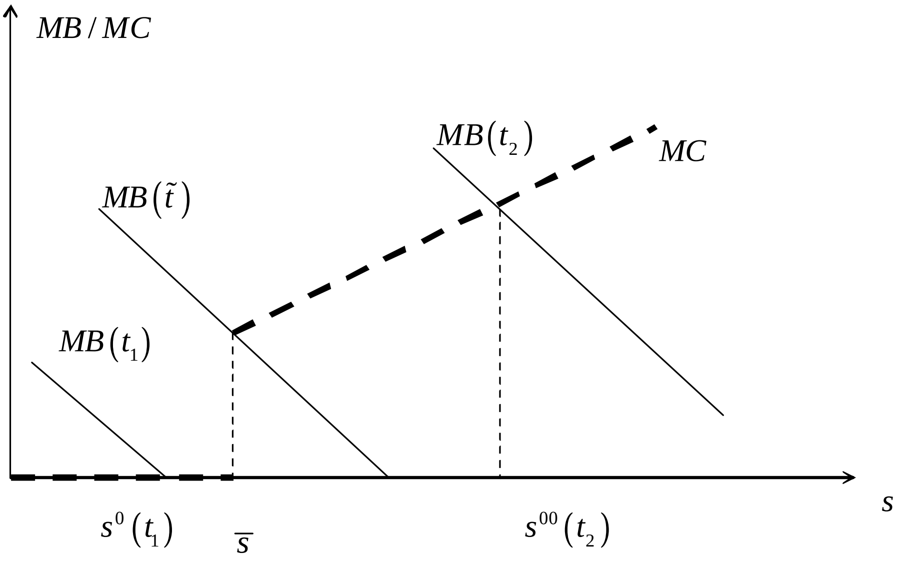
The driver will speed if the utility of complying is lower than the benefit of violating and risking the fine. There exists a certain value of time for which drivers are indifferent between speeding or not $(D = 0)$. This cut-off point $\tilde{t}$ is a function of π and $j\,(s)$ and is defined by the equality of the net driving cost without speeding (speed s^0) and the net driving cost of speeding (speed s^{00})

$$\left[C_T\left(\tilde{t},s^o\right)+C_M\left(s^o\right)\right]-\left[C_T\left(\tilde{t},s^{oo}\right)+C_M\left(s^{oo}\right)\right]-p\,R\left(j\,\left(s^{oo}\right)\right)=0 \qquad (12)$$

Given that the value of time is uniformly distributed, we know that a proportion $\frac{\tilde{t}-t_1}{t_2-t_1}$ of the N_c strong road users comply and a proportion $\frac{t_2-\tilde{t}}{t_2-t_1}$ speed.

We show the speed decision in Figure 3. 1. On the horizontal axis we denote the speed level and on the vertical axis the marginal costs and benefits. The upward sloping curve (dashed line) is the marginal cost of speeding and the downward sloping curves represent the marginal benefits for each value of time. People with a value of time $t_1 < \tilde{t}$ comply with the speed limit, while people with a value of time such as $t_2 > \tilde{t}$ speed.

Figure 3. 1: The speed decision of the car drivers



(c). Government

The government receives the net fine revenues (probability of detection times the fine times the number of offences minus the cost of enforcement) and uses this revenue to give a lump sum *L* to all road users *N*.

$$p\frac{N_c}{t_2-t_1}\overline{ac}_c\int_{t_1}^{t_2}\left(j\left(s(t)\right)-C_E^V\right)dt-C_E^F=LN \tag{13}$$

Rewriting (13) gives the following expression for the lump sum transfer

$$L=\frac{p\frac{N_c}{t_2-t_1}\overline{ac}_c\int_{t_1}^{t_2}\left(j\left(s(t)\right)-C_E^V\right)dt-C_E^F}{N} \tag{14}$$

Note that individuals, when they decide to speed or not, do not perceive the influence of the fine they pay on the lump sum transfer, because there is a large number of car drivers N_c.

Following Dixit et al (1997), we assume that the outcome of the lobbying game can be represented by the maximum of a function that equals a weighted sum of a social welfare function (representing the pure political process before lobbying) and the utility functions of the lobbying groups.

$$OBJ(q,l)=qSWF+(1-q)\left[l N_v V_v+[1-l]N_c V_c\right] \tag{15}$$

The weights $(q \text{ and } l)$ are determined by the lobbying game. If $q=1$, lobbying has no influence on the policy decision and the regulator selects the monitoring and enforcement strategy that maximises social welfare. If $q = 0$, only lobbies matter and then the parameter l determines the relative power of each lobby group. In this paper we assume that the outcome of the purely political process (SWF) corresponds to the maximum of an additive utilitarian social welfare function[49].

In the next section, we determine analytically the socially optimal probability of detection and the associated fine function. In the following section, we numerically calculate these parameters. Moreover we also numerically analyse the choice between the probability of detection and the fine function when the expected fine is given.

3. THE OPTIMAL FINE FUNCTION AND PROBABILITY OF DETECTION

We first consider the benchmark case, where the government simply maximises the objective function (15) with respect to the probability of detection p, the fixed fine ff and the variable fine vf in the absence of any lobby groups $(q = 1)$. Next, we examine two extreme lobbying equilibriums: one where the vulnerable road users have all the lobbying weight $(q = 0,\ l = 1)$ and one where only the utility of the strong road users is taken into account $(q = 0,\ l = 0)$. We show in what direction interest groups want to influence the monitoring and enforcement strategy.

(a). Benchmark: $q = \mathbf{1}$

In the benchmark, there are no lobby groups and we assume that this results into the maximisation of an additive utilitarian social welfare function. This implies that the utility of each individual has the same weight.

---

[49] We can take other assumptions but this would require us to model more finely the working of the political process itself.

$$
\begin{aligned}
SWF &= N_v V_v + N_c V_c = N_v V_v + \frac{N_c}{t_2 - t_1}\left[\int_{t_1}^{\tilde{t}} V_c\left(comply\right)dt + \int_{\tilde{t}}^{t_2} V_c\left(speed\right)dt\right] \\
&= N_v\left[Y_v + L + \overline{ac}_v\left[g_v - p\left(s\right)h\right]\right] \\
&\quad + \frac{N_c}{t_2 - t_1}\int_{t_1}^{\tilde{t}}\left[Y_c + L + \overline{ac}_c\left[g_c - C_T\left(t,s\right) - C_M\left(s\right)\right]\right]dt \qquad (16) \\
&\quad + \frac{N_c}{t_2 - t_1}\int_{\tilde{t}}^{t_2}\left[Y_c + L + \overline{ac}_c\left[g_c - C_T\left(t,s\right) - C_M\left(s\right) - pR\left(j\left(s\right)\right)\right]\right]dt
\end{aligned}
$$

Using Leibnitz' rule and restricting ourselves to a linear fine function, we calculate the derivatives of social welfare with respect to p, ff and vf. These first order conditions form a system of three equations and three unknowns.

The first order condition for the inspection frequency is:

$$
\frac{dSWF}{dp} = \left[\begin{array}{l}
\underbrace{N_v\left[-\frac{dp\left(s\right)}{dp}h\right]\overline{ac}_v}_{\textit{decreased accident cost}} \\
\underbrace{+\frac{N_c}{t_2 - t_1}\overline{ac}_c\int_{t_1}^{t_2}\left[\begin{array}{l}
-\frac{dC_T\left(t,s\right)}{dp} - \frac{dC_M\left(s\right)}{dp} \\
-p\left[a + b\left(ff + vf\left(s - \overline{s}\right)\right)vf\frac{ds}{dp}\right] \\
-\left[a\left(ff + vf\left(s - \overline{s}\right)\right) + \frac{b}{2}\left(ff + vf\left(s - \overline{s}\right)\right)^2\right]
\end{array}\right]dt}_{\textit{change trip cost}} \\
\underbrace{+\frac{N_c}{t_2 - t_1}\overline{ac}_c\int_{\tilde{t}}^{t_2}\left[\left(ff + vf\left(s - \overline{s}\right)\right) + p\,vf\frac{ds}{dp} - C_E^V\right]dt - pC_E^V\frac{d\tilde{t}}{dp}}_{\textit{change in government revenue from fines}}
\end{array}\right] = 0 \quad (17)
$$

Using expression (10), we have:

$$\begin{bmatrix} \underbrace{N_v \left[-\frac{dp(s)}{dp} h \right] \overline{ac}_v}_{\textit{decreased accident cost}} \\ \underbrace{+\frac{N_c}{t_2 - t_1} \overline{ac}_c \int_{t_1}^{t_2} \left[-\left[a \left(ff + vf\left(s - \overline{s} \right) \right) + \frac{b}{2} \left(ff + vf\left(s - \overline{s} \right) \right)^2 \right] \right] dt}_{\textit{disutility fine}} \\ \underbrace{+\frac{N_c}{t_2 - t_1} \overline{ac}_c \int_{\tilde{t}}^{t_2} \left[\left(ff + vf\left(s - \overline{s} \right) \right) + p\,vf \frac{ds}{dp} - pC_E^V \right] dt - pC_E^V \frac{d\tilde{t}}{dp}}_{\textit{change in government revenue from fines}} \end{bmatrix} = 0 \qquad \forall s \geq \overline{s}$$

The socially optimal probability of detection is determined by equating the marginal cost of increasing the probability to the associated marginal benefit. The marginal benefit equals the decrease in accident cost. If p increases for given vf and ff, the speed on the roads decreases and thus the expected accident costs decrease. The marginal cost equals the disutility of the fine. However, the change in government revenue is uncertain because two opposite effects play. Firstly, due to the relative increase in the expected fine, there are fewer speeders, the chosen speed is lower and the variable enforcement costs are higher. Hence government revenue decreases (a cost). On the other hand, additional revenue is created because the expected fine is higher and, because there are fewer speeders, the variable enforcement costs decrease (a benefit).

Next, the fixed fine is determined by the following expression:

$$\frac{dSWF}{dff} = \begin{bmatrix} \underbrace{N_v \left[-\frac{dp(s)}{dff} h \right] \overline{ac}_v}_{\textit{decreased accident cost}} \\ \underbrace{+\frac{N_c}{t_2 - t_1} \overline{ac}_c \int_{t_1}^{t_2} \begin{bmatrix} -\frac{dC_T(t,s)}{dff} - \frac{dC_M(s)}{dff} \\ -p \left[a + b\left(ff + vf\left(s - \overline{s} \right) \right) vf \frac{ds}{dff} \right] \end{bmatrix} dt}_{\textit{change trip cost}} \\ \underbrace{+p \frac{N_c}{t_2 - t_1} \overline{ac}_c \left[t_2 - \tilde{t} - C_E^V \frac{d\tilde{t}}{dff} \right]}_{\textit{change in government revenue from fines}} \end{bmatrix} = 0 \qquad (18)$$

Note that the change in the trip costs equals zero (cf. equation (10)). Hence, the socially optimal ff is determined by equating the change in government revenue to the decrease in accident costs.

$$\left[\underbrace{N_v\left[-\frac{dp(s)}{dff}h\right]\overline{ac}_v}_{\text{decreased accident cost}}+\underbrace{p\,\frac{N_c}{t_2-t_1}\overline{ac}_c\left[t_2-\tilde{t}-C_E^V\,\frac{d\tilde{t}}{dff}\right]}_{\text{change in government revenue from fines}}\right]=0 \qquad \forall s\geq\overline{s}$$

The socially optimal variable fine vf is determined in a similar way as the fixed fine ff .

$$\frac{dSWF}{dvf}=\left[\underbrace{N_v\left[-\frac{dp(s)}{dvf}h\right]\overline{ac}_v}_{\text{decreased accident cost}}+\underbrace{p\,\frac{N_c}{t_2-t_1}\overline{ac}_c\left[\int_{\tilde{t}}^{t_2}(s-\overline{s})\,dt-C_E^V\,\frac{d\tilde{t}}{dvf}\right]}_{\text{change in government revenue from fines}}\right]=0 \qquad \forall s\geq\overline{s} \tag{19}$$

The three monitoring and enforcement parameters are determined by equating the marginal cost to the marginal benefits. The exact magnitudes of vf , ff and p depend on the way the speed decisions react to the change in the probability of detection, the change in the fixed fine or the change in the variable fine. These reactions depend on the degree of risk aversion.

Note that we cannot guarantee a unique solution. Several combinations of vf , ff and p will have the same effect on drivers' compliance and are therefore indistinguishable. This scenario serves as a benchmark.

(b). $q=\mathbf{0}$ *and only the vulnerable road users lobby counts:* $l=\mathbf{1}$

When the government only takes the utility of the vulnerable road users into account, the objective function equals

$$OBJ(0{,}1)=N_vV_v \tag{20}$$

The optimal probability of detection is then determined by

$$\frac{dOBJ(0{,}1)}{dp}=0\Rightarrow N_v\,\frac{dL}{dp}+N_v\left[-\frac{dp(s)}{dp}h\right]\overline{ac}_v=0 \tag{21}$$

$$\Rightarrow\left[\begin{array}{l}\underbrace{N_v\left[-\dfrac{dp(s)}{dp}h\right]\overline{ac}_v}_{\text{decreased accident cost}}\\ \underbrace{+\dfrac{N_v}{N}\dfrac{N_c}{t_2-t_1}\overline{ac}_c\left(\displaystyle\int_{\tilde{t}}^{t_2}\left[\left(ff+vf\,(s-\overline{s})\right)+p\,vf\,\dfrac{ds}{dp}-C_E^V\right]dt-p\,C_E^V\,\dfrac{d\tilde{t}}{dp}\right)}_{\text{change in government revenue from fines}}\end{array}\right]=0 \tag{22}$$

For a vulnerable road user, the marginal benefits of improved monitoring are the reduction in accident costs and the (possible) increase in fine revenues of which she receives a share $\frac{N_v}{N}$ without having to pay them. The marginal costs of increased control are the higher monitoring costs. So the vulnerable road users do not take any effects on the private cost of the strong road users into account.

The fixed fine that is preferred by the vulnerable road users is determined by:

$$\frac{dOBJ\left(0{,}1\right)}{dff}\left[\underbrace{N_v\left[-\frac{dp\left(s\right)}{dff}h\right]\overline{ac}_v}_{\textit{decreased accident cost}}+\frac{N_v}{N}\underbrace{p\,\frac{N_c}{t_2-t_1}\overline{ac}_c\left[t_2-\tilde{t}-C_E^V\frac{d\tilde{t}}{dff}\right]}_{\textit{change in government revenue from fines}}\right]=0 \qquad \forall s\geq\overline{s}$$

This expression is very similar to the social optimum, except that only part of the change in government revenue is taken into account.

The variable fine in this scenario is found by solving:

$$\frac{dOBJ\left(0{,}1\right)}{dvf}=\left[\underbrace{N_v\left[-\frac{dp\left(s\right)}{dvf}h\right]\overline{ac}_v}_{\textit{decreased accident cost}}+\frac{N_v}{N}\underbrace{p\,\frac{N_c}{t_2-t_1}\overline{ac}_c\left[\int_{\tilde{t}}^{t_2}\left(s-\overline{s}\right)dt-C_E^V\frac{d\tilde{t}}{dvf}\right]}_{\textit{change in government revenue from fines}}\right]=0 \qquad \forall s\geq\overline{s}$$

Again we find a similar expression as for the social optimum but with only part of the change in government revenue taken into account.

(c). $q=\mathbf{0}$ *and only the strong road users lobby counts:* $l=\mathbf{0}$

In this scenario, the government only cares about the strong road users. The objective function then equals

$$OBJ(0{,}0)=N_cV_c \qquad (23)$$

The optimal probability of detection is derived from

$$\frac{dOBJ(0{,}0)}{dp}=0$$

$$\Rightarrow \begin{bmatrix} \underbrace{\frac{N_c}{t_2-t_1}\overline{ac}_c \int_{t_1}^{t_2} \left[-\left[a\left(ff + vf\left(s-\overline{s} \right) \right) + \frac{b}{2}\left(ff + vf\left(s-\overline{s} \right) \right)^2 \right] \right] dt}_{disutility\ fine} \\ + \frac{N_c}{N} \underbrace{\frac{N_c}{t_2-t_1}\overline{ac}_c \left(\int_{\tilde{t}}^{t_2} \left[\left(ff + vf\left(s-\overline{s} \right) \right) + p\, vf \frac{ds}{dp} - pC_E^V \right] dt - pC_E^V \frac{d\tilde{t}}{dp} \right)}_{change\ in\ government\ revenue\ from\ fines} \end{bmatrix} = 0 \qquad \forall s \geq \overline{s}$$

(24)

The possible benefit to the strong road users of more inspections is the change in government revenue, while the cost consists of the disutility of the fine. The strong road users do not take any effect on the accident costs into account and they only consider part of the enforcement cost and the government revenues. In order to determine the fine parameters, ff and vf, they only take part of the change in government revenue into account. Thus the first order conditions for the fixed and variable fine parameters are:

$$\frac{dOBJ\left(0,0\right)}{dff} \left[\frac{N_c}{N} p \underbrace{\frac{N_c}{t_2-t_1}\overline{ac}_c \left[t_2 - \tilde{t} - C_E^V \frac{d\tilde{t}}{dff} \right]}_{change\ in\ government\ revenue\ from\ fines} \right] = 0 \qquad \forall s \geq \overline{s}$$

$$\frac{dOBJ\left(0,0\right)}{dvf} = \left[\frac{N_c}{N} p \underbrace{\frac{N_c}{t_2-t_1}\overline{ac}_c \left[\int_{\tilde{t}}^{t_2} \left(s - \overline{s} \right) dt - C_E^V \frac{d\tilde{t}}{dvf} \right]}_{change\ in\ government\ revenue\ from\ fines} \right] = 0 \qquad \forall s \geq \overline{s}$$

(d). Discussion

In order to compare the solutions preferred by the vulnerable and strong road users with respect to the probability of detection and the level of the fine, we need to distinguish two cases. In the first case, when the monitoring and enforcement policy is strengthened, the change in government revenue is positive or, in other words, the lump sum distributed to the individuals increases; in the second case the change in government revenue is negative and thus the level of the lump sum transfer decreases (and can even be negative if the cost of enforcement is higher than the fine revenue).

Concentrating on the probability of detection, we find that the social optimum value is higher than the probability of detection preferred by the strong road users if the government budget grows. The ordering with respect to the vulnerable road user is undetermined. For the fixed and the variable fine, we find that the social optimum value is always higher than the fine preferred by the vulnerable and the strong road user. A sufficient condition for the fixed fine preferred by the vulnerable road users to be higher than the one chosen by the strong road user is.

$$N_v \left[\frac{dp}{dp} h \right] \overline{ac}_v > \left(\frac{N_c - N_v}{N} \right) \frac{N_c}{t_2 - t_1} \overline{ac}_c \left(t_2 - \tilde{t} - p\, C_E^V \frac{d\tilde{t}}{dp} \right),$$

This is, the marginal benefit curve for the vulnerable road user is higher than that for the strong user. The condition for the variable fine is analogous.

In the second case, if the government revenue is decreasing, the probability of detection, the fixed and the variable fine preferred by the vulnerable road users are higher than the social optimal one. The ordering with respect to the strong road users' preference is undetermined.

In the next section we specify the different functions so that numerical simulations can help in ranking the different solutions preferred by the distinct interest groups.

4. NUMERICAL EXERCISE - ILLUSTRATION

We illustrate the theoretical analysis by means of a numerical example and investigate the impact of lobbying activity on the selection of monitoring and enforcement parameters for speed limitations for two scenarios. In the first case p, ff and vf can be set freely, in the second the expected fine is fixed. After mentioning the underlying assumptions, this section describes and discusses the results.

4.1. Assumptions

We consider interurban roads in Belgium where the current speed limit is 90 km/h. Table 3.1 summarizes the assumptions we make with respect to the proportion of vulnerable road users, the number of trips they make on an average day, the utility of a trip and their income per day.

Table 3. 1: Trip parameters

	Prop. of Population	# Trips /day	Utility (€) /trip	Income (€) /day
Vulnerable road users	0,234	0,8	5,9	50
Strong road users	0,766	2,2	35	50

Source: Toint (2001), own calculations

The private cost of driving a car equals the sum of the resource cost, the fuel cost and the time cost. The resource cost comprises the purchase cost, the insurance, the maintenance, etc. We assume that it is independent of the level of speed and equal to 0,23551 Euro/km[50]. The fuel cost depends on the fuel price and fuel use. Both elements depend on the type of fuel. We assume that 49% of the cars drive on gasoline and 51% on diesel[51]. The price of diesel equals 1,141 Euro/litre and the price of gasoline equals 1,415 Euro/litre[52]. The fuel use depends on the fuel type and the speed. The different functions are given in Table 3. 2 where s is the speed in km/h.

Table 3. 2: Fuel use

Fuel type	Speed range	Fuel use (l/km)
Diesel	10-130 km/h	$0{,}1377779 - 0{,}00242356\, s + 0{,}000016279\, s^2$
Gasoline	80-130 km/h	$0{,}0395757 + 0{,}0006365\, s$

MEET project (1998), International Energy Agency (2002)

The time cost equals the value of time divided by the level of speed. We consider fifteen values of time ranging from 4 Euro/hour to 40 Euro/hour and assume that these values are uniformly distributed among the strong road users.

---

[50] Own calculations based on De Borger and Proost (1997).

[51] NIS 2005 Website

[52] www.petrolfed.be

The expected accident cost equals the harm times the accident risk. For the harm caused by a serious accident we use a value of 2.000.000 Euro. Using the data from the FOD Economics (2006), we calculate the accident risk $\left(p(s)\right)$ per km for accidents between vulnerable and strong road users, taking into account the influence of speed on the accident risk[53]. We use the following expression:

$$p(s) = 0{,}000002154*\left(\frac{s}{\text{speed limit}}\right)^3 \tag{25}$$

We assume that the cost of enforcement takes the following form

$$C_E(p) = 20500 + 410\frac{t_2 - \tilde{t}}{t_2 - t_1}N_c p^2 \tag{26}$$

with the fixed enforcement cost equal to 20500 Euro and the variable enforcement costs equal to 410 Euro times the number of violators.

Remember that we use the following structure for speeding fines

$$j(s) = ff + vf(s - 90) \tag{27}$$

This means that if you speed you pay a fixed fine of ff Euro and an additional fine vf per km/h over the speed limit.

4.2. *Results and discussion*

In this exercise, we first determine the probability of detection π, the fixed fine ff and the variable fine vf when all variables can be set freely. Secondly, we determine these parameters for a given expected fine function. In the two cases the optimal monitoring and enforcement parameters are calculated for three different scenarios: (i) the benchmark $(q = 1)$, (ii) the vulnerable road users' utility function is maximised $(q = 0 \ and \ l = 1)$ and (iii) the strong road users' utility function is maximised $(q = 0 \ and \ l = 0)$.

In the first setting, when the variables can be set freely, we use a heuristic approach to find the different optima and calculate the objective functions for 2800 different combinations of the three variables under the following conditions:

---

[53] Elvik et al (2000) provides a formula which relates the accident risk to the speed.

$$0{,}0001 \leq p \leq 0{,}2501$$
$$0 \leq ff \leq 75$$
$$0{,}0001 \leq vf \leq 30{,}0001$$

Table 3. 3 shows the results for this scenario. As expected, we find that the vulnerable road users opt for a solution where the number of speeders is minimised whereas the strong road users opt for the minimal expected fine. The social optimum lies in between. When there are more vulnerable road users, the social optimum will involve a solution with fewer speeders than in this example. Note that in this example the solutions for the strong road users and the social optimum are unique – this is not the case for the solution favoured by the vulnerable road users. This makes sense because different combinations ensure that all comply.

Table 3. 3: Preferred policies

	No lobby	Lobbying only by vulnerable road users	Lobbying only by strong road users
p /trip	0,0001	0,0101	0,0001
vf (€)	30,0001	6,0001	0,0001
ff (€)	45	0	0
SWF (€)	90.178	90.175	90.040
# speeders (%)	73,3	0	93,3

Own calculations.

Next we look at the speeding decisions made be car drivers. As expected, the chosen speed level rises if the driver’s value of time increases (see Table 3. 4). We also see that the selected monitoring and enforcement policy can drastically reduce the number of violators. In the private optimum without enforcement 93,3 % of the car drivers violate the speed limit, while no one does so under the policy favoured by the vulnerable road users. The social optimum still allows 73 percent of the drivers to speed despite the risk of accident.

Table 3. 4: Speed decision in benchmark

Value of time (€/h)	Private optimal speed (no enforcement)	Speed (enforcement= social optimum)	Speed (enforcement as preferred by vulnerable users)	Speed (enforcement as preferred by strong users)
4	82,31	82,31	82,31	82,31
7	93,45	90,00	90,00	93,45
8	96,49	90,00	90,00	96,49
9	99,31	90,00	90,00	99,31
10	101,92	96,55	90,00	101,92
11	104,41	99,13	90,00	104,41
12	106,74	101,57	90,00	106,74
14	111,06	106,06	90,00	111,06
16	115,00	110,16	90,00	115,00
18	118,64	113,93	90,00	118,64
20	122,03	117,44	90,00	122,03
25	129,65	125,31	90,00	129,65
30	136,34	132,19	90,00	136,34
35	142,33	138,36	90,00	142,33
40	147,80	143,98	90,00	147,80

Own Calculations

In the second scenario, we use non-linear programming in order to select the monitoring and enforcement parameters that maximise the different objective functions under the restriction of a constant expected fine function. Following Polinsky and Shavell (2000), the expected fine function is determined exogenously as the sum of the change in the expected harm plus the variable enforcement cost. This is

$$\left(pj\ (s)\right)^{*} = \Delta p(s)\, harm(s-90) + ve \qquad (28)$$

Remember that we can not calculate a unique socially optimal expected fine function. The results are summarised in Table 3. 5.

Table 3. 5: Preferred policies when the expected fine is fixed

	No lobby	*Lobbying only for vulnerable road users*	*Lobbying only for strong road users*
p /trip	0,0677	0,04	0,54
vf (€)	1,29	2,18	0,16
ff (€)	590	1000	73
SWF (€)	90.160	90.160	90.160
# speeders (%)	0	0	0

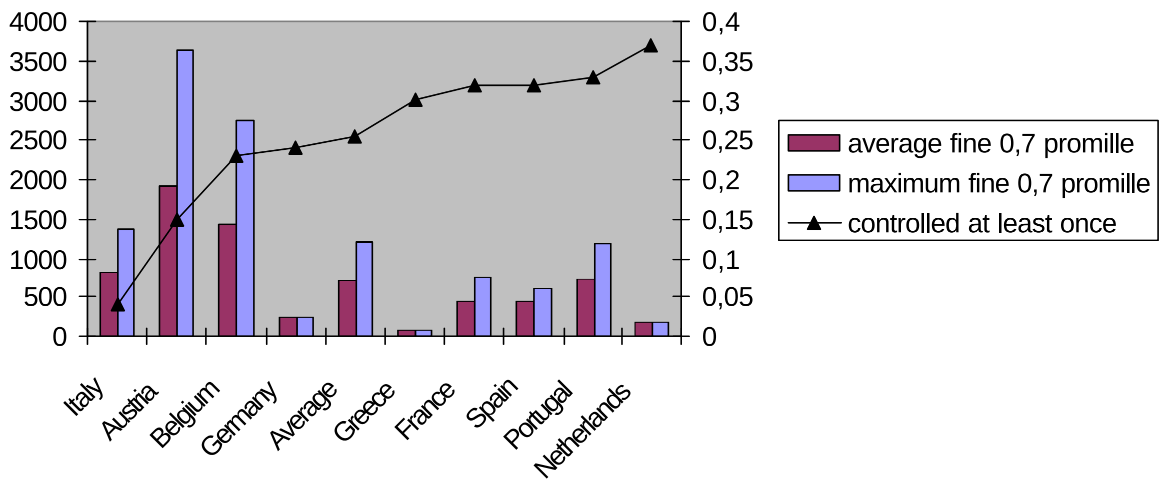
Own Calculations

This illustration corresponds with the second case discussed for the theoretical model. In line with our expectations, we indeed see that the strong road users opt for a lower fine function and a higher probability of detection than the vulnerable road users. After all, the strong road users are the only ones to pay the fines while the burden of increasing the inspection probability is shared with the vulnerable road users. Without lobbying, the social optimum lies, as expected, in between these two extremes.

5. CONCLUSION AND SOME EMPIRICAL EVIDENCE

In the context of road safety and more specifically speed limits, we develop a model that represents the preferences of different lobby groups. In the model, the lobby groups can select different combinations of inspection probability and fine level. We show – both theoretically and numerically - that, in general, vulnerable road users (cyclists, pedestrians) prefer a higher expected fine than strong road users (car and truck drivers). If we focus on the choice between the magnitude of the fine and the inspection probability for a given fixed expected fine, we find that the vulnerable road users prefer a higher fine and a lower inspection frequency than the strong road users. This model can not only be used to explain current policy in one country but it could also serve to clarify differences in policy between countries or regions. As a case in point, traffic safety stands high on the political agenda in Flanders, a region in Belgium, and many resources are spent to improve traffic safety. This is less the case in Wallonia, another region in the same country. For example, Flanders wants to lower the speed limit on interurban roads to 70 km/h, while Wallonia wants to keep the 90 km/h speed limit. A possible approach to investigate the variation in regional policies could be, for example, to look at the shares of vulnerable and strong road users and the type of enforcement policy in place and calculate the correlation coefficient. One could also perform an econometric analysis to determine the exact influence of the interest groups. However, there are two problems: there are too little observations and information on the probability of detection is often lacking. Another illustration is the enforcement strategy chosen by nine European countries for drunk driving. Figure 3. 2 shows the average and the maximal fines for drunk driving (between 0.5 and 0.7 promille) for some European Countries. The percentage of people who have been checked at least once for drunk driving serves as an indicator for the probability of detection.

Figure 3. 2: Probability of detection and fines for alcohol infractions



Source: SARTRE (2004), Van den Houten, M.; Rademaker, J. (2005)

We make three observations. Firstly, there is a lot of variation in the enforcement strategies. Secondly, in general, the fines decrease as the probability of detection increases. In Table 3. 6 we confront the enforcement strategy with the relative importance of vulnerable road users. We see that in countries where there are relatively many vulnerable road users, the fines are higher and the probability of detection lower (except for Germany and the Netherlands). This is our third observation.

Table 3. 6: Importance of vulnerable road users

Country	*Relative number of km travelled by vulnerable road users compared to European average*
Greece	0,6656
Spain	0,696
Portugal	0,7568
France	0,8224
Average	1
Italy	1,0032
Austria	1,0208
Germany	1,16
Belgium	1,2336
The Netherlands	2,0736

Own calculations based on Eurostat (2007)

Furthermore, the analysis is not restricted to the setting of fines and probability of inspections for speeding or drunk driving. Nor is it limited to vulnerable versus strong road users or to enforcement. Other types of (road) users such as freight versus passenger transport, pedestrians versus cyclist, etc. can be discussed as long as their objective functions can be clearly defined. The model can also provide additional insights into the political processes that determine the monitoring and enforcement strategies for, for example, environmental legislation. Moreover, notice from Table 4. 1 in chapter 4 that in exactly those countries where there are relatively more vulnerable road users, a different liability rule is in place for accidents with only motorised vehicles than for accidents between vulnerable and motorised road users.

Note that we did not discuss the political process behind the objective function of the government as this is beyond the scope of this paper. Furthermore, we did not take into account any equity effects the enforcement policy may have; nor did we consider the case where all users are – to some extent – risk averse. Finally, we assumed that the fine revenues were redistributed in a lump sum fashion. In reality, these revenues are often earmarked. If, for example, all revenue is used for investments in traffic safety, this lowers the general accident risk and hence creates an additional incentive for the vulnerable road users to set the expected fine at revenue maximising levels.

4

Will the Cyclist Take Care Simply because He Might Get Hurt?

Eef Delhaye

1. INTRODUCTION

The question considered in this paper is how liability rules affect the incentives of vulnerable road users and hence road safety. In general, liability rule systems determine who pays for the damage done if an accident occurs. Consequentely the accident costs enter the decision making process of the road users and influence their behaviour. Hence, the liability rule in place influences traffic safety. Shavell (1987, 2004) and Cooter and Ulen (2004) provide very comprehensive overviews of the influence of liability rules on agents' decision making. However, in practice many countries require mandatory[54] car insurance. The liability rules then determine whose insurance has to pay and the question then becomes: how does the insurance company influences the behaviour of their insured? We will briefly comment on the influence of introducing insurance in section 7, but the focus of this chapter is the pure influence of liability rules.

---

[54] There are different reasons for making (car) insurance mandatory. For example, to prevent averse selection, to overcome the judgment proof problem (this is the problem that the injurer cannot pay for the damages done), to provide sure and quick compensation for the victim, etc. (Shavell, 2004; Van den Bergh, 1998). We will not discuss this further.

When we consider European legislation, shown in Table 4. 1, we find that in many countries a different liability rule applies for accidents between motorised users than for accidents between a motorised user and a vulnerable road user, such as pedestrians, cyclists, etc.

Table 4. 1: Liability for traffic accidents in Europe

Country	*Liability car-car accidents*	*Liability car-bicycle accidents*	*Indicator vulnerable road users*[a]
Austria	Negligence	Strict liability	1.021
Belgium	Comparative Negligence	Strict liability for personal injury	1.234
Denmark	Negligence for material losses Strict liability for personal injury	Negligence for material losses Strict liability for personal injury	n.a.[b]
Germany	Strict Liability with the defence of Force Majeure for car drivers Negligence for personal injury	Strict Liability with the defence of Force Majeure for car drivers Negligence for personal injury	1.160
Finland	Negligence	Strict liability	n.a.
France	Negligence	Strict liability	0.822
Greece	Negligence	Negligence	0.666
Ireland	Comparative Negligence	Comparative Negligence	n.a.
Italy	Negligence + suspicion of guilt	Negligence + suspicion of guilt	1.003
Luxemburg	Negligence presumed with the defence of Force Majeure for car drivers	Negligence presumed with the defence of Force Majeure for car drivers	0.765
The Netherlands	Negligence	Strict liability for 100% if cyclist < 14y for minimum 50% if older	2.074
Norway	No fault	No fault	n.a.
Portugal	Strict Liability with defence of contributory negligence	Strict Liability (no defence)	0.757

Spain	Strict liability for personal injuries Negligence for other damages	Strict liability for personal injuries Negligence for other damages	0.696
Sweden	No fault for personal injuries (own insurer pays) Negligence for material damages	No fault for personal injuries (insurer of any of the cars involved pays) Negligence for material damages	n.a.
UK	Negligence	Negligence	0.787
Switzerland	Strict Liability with defence of contributory negligence	Strict Liability with defence of contributory negligence	n.a.

[a] If >1, the proportion of vulnerable road users with respect to ‘strong’ road users is larger than the European average.
[b] n.a. = Data not available
European Federation of Road Traffic Victims (2005), own calculations based on Eurostat (2007)

On the one hand, in the majority of the countries a rule of negligence applies for accidents between motorised users. On the other hand, if a vulnerable road user is involved, in most countries only the motorised road user is liable for the accident. This might be analysed using a similar model as in chapter 3 as it are the countries with a relatively high proportion of vulnerable road users who have a different liability rule for car-car accidents than for car-bicycle accidents. Countries with less vulnerable road users tend to have the same liability rule for both types of accidents. In this chapter we take another approach. We focus on the argument used by policy makers to have a different rule and that is that a vulnerable road user risks his life and limbs and therefore acts careful even though he is not liable. The effect of these so-called non-pecuniary losses are discussed by Shavell (1987, chapter 10), Arlen (1990, 1992), Visscher (1998) and Visscher et al. (1998). However, Shavell (1987) has assumed that only one party influences the accident, while it is clear that both parties - the vulnerable road user and the motorised user – influence the accident risk. For instance, both parties can take precautions such as wearing a reflective jacket or adapting the speed. Arlen (1990, 1992) has only examined the influence of the level of care and not the activity level. Visscher (1998) and Visscher et al. (1998) discusses accidents between a car and a vulnerable road user where both influence the probability of an accident. However, he implicitly assumes that people are risk neutral.

This contribution takes into account that both parties influence the probability of an accident, that the level of care and activity play a role, that utilities are state dependent and that people are risk averse. We investigate how a strict liability rule influences the behaviour of the vulnerable road user: is the risk of life and limbs sufficient to take care or will he behave recklessly because he is always compensated? Will this rule lead to the social optimum? If not, would a negligence rule perform better? What happens if we introduce insurance?

First, we define the possible liability rules that the government can use. We then set up the model and find out what happens if the government does not intervene – this is the private optimum. Next, we determine the social optimum and analyse the performance of the three most common liability rules: strict liability, negligence and comparative negligence. We answer the following question: can the existing system be justified on economic grounds or is there another rule which performs better? Finally, given that insurance greatly affects the working of the liability rule, we briefly discuss insurance.

We find that – in general – the incentives for vulnerable and motorised road users to take care are better under a rule of negligence than under strict liability. However, under a rule of negligence the activity level is not controlled directly. If it is very important to control the activity and the care of the motorised driver, the rule of strict liability performs best. If we want to control the level of care and activity level of both types, the best option would be to supplement a rule of negligence with for example a km tax or with an insurance per km.

For the ease of reading we talk about cyclists and car drivers in stead of vulnerable road users and motorised users in the remainder of the text. The word road user can stand for a pedestrian, a cyclist or a car driver.

2. LIABILITY RULES

To start, a non-exclusive enumeration of possible liability rules[55] is given. We define the different rules, using the example of a car-cyclist accident. In the formal analysis, we only consider four of them – this is no liability, strict liability, negligence and comparative negligence. Each road user k takes a level of care x_k $\left(k = h,v\right)$ with h the injurer and v the

---

[55] Based on Shavell (1987) and Cooter and Ulen (2004). Note that this overview only focuses on the effects on the level of care, while there is also an effect – although more indirectly – on the level of activity.

victim. Care can be interpreted very broadly. It can be looking in the rear mirrors, obeying the speed limits and other traffic regulations, adapting the driving style to weather conditions, etc. However, in practice - and in this paper - care is interpreted as everything that can be controlled and monitored. For example, a judge cannot control the number of times a car driver looks into the rear mirror but he can measure the speed at the time of the accident.

(a). *No Liability.*

Each road user bears his/her own losses. Note that this is the same as the private optimum.

(b). *Strict Liability.*

The car driver must pay for all accident losses that he caused. This is the rule in use for accidents between car drivers and vulnerable road users in various European countries[56].

(c). *Negligence Rule.*

The injurer[57] is liable for the accident losses he caused only if he was negligent, that is, only if his level of care was less than a level specified by courts, called “due care”.

x_h^*: due care level of the injurer

injurer at fault $(x_h < x_h^*) \rightarrow$ injurer liable

injurer faultless $(x_h \geq x_h^*) \rightarrow$ injurer not liable, victim bears own losses,

irrespective of his level of care $((x_v \geq x_v^*), (x_v < x_v^*))$

---

[56] For example in Belgium, Article 29bis of Belgian Act of 21 November 1989 states that ‘in the event of a traffic accident in which a motor vehicle is involved, all damages with exception of the material losses of the victim or his claimant, consequent to injuries or death, have to be compensated by the insurer which covers the liability of the owner, the driver or the holder of the motor vehicle’. This compensation is due regardless of who was at fault. Hence we are dealing with strict liability. Some argue that we are dealing with strict liability with the defence of contributory negligence since §1, part 5 states that ‘victims who are older than 14 years and wanted the accident and its consequences cannot call for the provisions of this article’. This is a very strong condition, only fulfilled in the case of a suicide attempt, which is not the most common accident type. Hence, we think it is more correct to interpret this as a strict liability rule.

[57] The injurer can be the car driver and/or the cyclist. Both influence the probability of an accident, hence both can be an injurer. Moreover both can have losses and hence be a victim.

(d). Strict Division of Accident Losses.

Both parties each bear a positive fraction of the total accident losses that occur. The fraction is assumed to be independent of their level of care.

(e). Strict Liability with the Defence of Contributory Negligence.

The injurer is liable for the accident losses he causes unless the victim's level of care was less than his due care level.

x_v^*: due care level of victim

victim faultless $(x_v \geq x_v^*) \rightarrow$ injurer liable,

irrespective of his level of care $((x_h \geq x_h^*), (x_h < x_h^*))$

victim at fault $(x_v < x_v^*) \rightarrow$ injurer not liable

(f). Strict Liability with the Defence of Dual Contributory Negligence.

The negligence criterion is applied to both the injurer and the victim. The victim only bears the losses if he is negligent and the injurer takes care; in all the remaining cases the injurer pays.

x_v^*: due care level of victim

x_h^*: due care level of injurer

victim at fault $(x_v < x_v^*)$, injurer faultless $(x_h \geq x_h^*) \rightarrow$ injurer not liable

victim at fault $(x_v < x_v^*)$, injurer at fault $(x_h < x_h^*) \rightarrow$ injurer liable

victim faultless $(x_v \geq x_v^*)$, injurer at fault $(x_h < x_h^*) \rightarrow$ injurer liable

Both at fault $[(x_h < x_h^*), (x_v < x_v^*)] \rightarrow$ injurer liable *(g). Strict Liability with the Defence of Relative Negligence.*

The injurer is liable for the accident losses he caused if the victim took due care. However, if the victim failed to take due care, the victim does not bear all the losses; rather he bears only a fraction of them. This fraction depends on his actual level of care relative to due care.

x_k^* : due care level of party k

injurer at fault $(x_h < x_h^*)$, and victim faultless $(x_v \geq x_v^*) \rightarrow$ injurer bears 100%

injurer faultless $(x_h \geq x_h^*)$, and victim at fault $(x_v < x_v^*) \rightarrow$ victim bears X%, with X=f(x_v / x_v^*)

Both at fault [$(x_h < x_h^*), (x_v < x_v^*)$]$\rightarrow$ injurer liable

(h). Negligence rule with the Defence of Contributory Negligence.

The injurer is not liable for the accident losses he caused if he takes at least due care; even if he does not, he still escapes liability if the victim fails to take due care.

x_k^* : due care level of party k

injurer faultless $(x_h \geq x_h^*) \rightarrow$ injurer not liable

injurer at fault $(x_h < x_h^*)$, and victim at fault $(x_v < x_v^*) \rightarrow$ injurer not liable

injurer at fault $(x_h < x_h^*)$, and victim faultless $(x_v \geq x_v^*) \rightarrow$ injurer liable

Both at fault [$(x_h < x_h^*), (x_v < x_v^*)$]$\rightarrow$ victim bears all the losses

(i). Comparative negligence rule.

If only one of the parties is at fault, that party bears all the losses. But if both injurer and victim fail to take due care, each party bears a fraction of accident losses. The fraction is determined by comparing the amount by which the two parties' levels of care depart from the levels of due care[58]. Together with negligence and strict liability this is the most often used rule for determining liability in traffic accidents.

---

[58] For example, Article 1382 of the Belgian Civil Code is the general article on tort liability. This article states that 'every deed of man, which by his fault causes damage to someone, obligates him to compensate for these damages'. The fault is determined by not exerting due care. This due care is, for example, obeying the traffic

x_k^* : due care level of party k

injurer at fault $(x_h < x_h^*)$, and victim faultless $(x_v \geq x_v^*) \rightarrow$ injurer bears 100%

injurer faultless $(x_h \geq x_h^*)$, and victim at fault $(x_v < x_v^*) \rightarrow$ victim bears 100%

Both at fault [$(x_h < x_h^*), (x_v < x_v^*)$]$\rightarrow$ injurer and victim bear in proportion to negligence

Both faultless [$(x_h \geq x_h^*), (x_v \geq x_v^*)$]$\rightarrow$ both bear their own losses

3. MODEL

We analyse the influence of four liability rules - no liability, strict liability, negligence and comparative negligence - on the behaviour of car drivers and cyclists. In order to do so, we first set up the model and calculate the outcome if the government does not intervene. This is the no liability case or the private optimum. Next, we derive the social optimum and see how the three other liability rules perform with respect to the social optimum.

We consider accidents between a car driver i and a cyclist j. Road users $(k = i, j)$ have two decisions to make: they choose whether and how many trips they make – the activity level ac_k and they decide on the level of care x_k they will exert ***(a1)***[59]. We assume that they make these decisions by maximising their expected utility ***(a2)***. Note that people are either car drivers or cyclists; their type does not depend on the rule in place.

We assume that both road users influence the probability of an accident p by their level of care and their activity, $p \equiv p\left(x_i, x_j, ac_i, ac_j\right), p_{x_k} < 0, p_{ac_k} > 0, p_{x_k ac_k} > 0$, $p_{x_i} = p_{x_j}, p_{ac_i} = p_{ac_j}$ ***(a3)***. The higher the level of care, the lower the probability of an accident and the higher the

---

rules. However obeying the traffic rules is not enough. One has to exert a general carefulness. Article 1382 also states that the victim is partly responsible if he does not exert due care. Hence, in Belgium, we are dealing with comparative negligence for all accident losses resulting from accidents between motorised vehicles and for the pecuniary losses of accidents between cars and cyclists.

[59] In order to ease the reading of this chapter we number the different assumptions.

activity level, the higher the probability of an accident[60] and both drivers affect the accident risk in the same way by their level of care and activity. Taking care comes at a cost c_k. This is a cost per activity unit. For example, the time losses due to driving slower, the cost of a reflective jacket for the cyclists, etc. Hence the total cost of taking care equals $c_k x_k ac_k$. We normalise the price of taking care to one[61], $c_k = 1, k = i, j$ ***(a4)***.

If an accident happens there is a pecuniary loss pl_k, for example, the damage to the car or the bike. If the accident also causes personal injury, this will affect both income and the marginal utility of income. The cost npl_k stands for the monetary losses caused by personal injury such as the medical expenses, future loss of income, etc. The marginal utility of income when injured may be higher if crippled by accident, even after being compensated for medical expenses and forgone income, because of the desire to obtain household help, special transportation services, etc. It might also be lower, because if crippled it is less pleasurable and more difficult to spend money (Shavell, 1987).

The utility, $U_k\left(w_k, ac_k, q\right)$ depends on the wealth w_k, the activity level ac_k and whether the person was involved in an accident ($q = 1$) or not ($q = 0$). In order to ease notation, we often use $U_{k|q=0}$ and $U_{k|q=1}$ in stead of $U_k\left(w_k, ac_k, 0\right)$ and $U_k\left(w_k, ac_k, 1\right)$. We assume for the sake of simplicity that all road users have the same initial wealth w_0 and that wealth equals this initial wealth minus the cost of taking care and the monetary losses when involved in an accident, $w_k = w_0 - 1 \cdot ac_k x_k - q\left(pl_k + npl_k\right)$ ***(a5)***. Furthermore, assume that utility increases

---

[60] If one does not drive, $ac_k = 0$, the probability of an accident is zero; if one drives this probability becomes positive. Hence, the probability of an accident increases with the level of activity. However, one could argue that people who drive a lot have more experience and are better drivers and hence that, after some level of activity, the accident risk decreases again with the activity level. It is most likely that the probability of an accident is a concave function of the activity level. Hence, we implicitly assume that the activity levels are such that we are on the increasing part of the function.

[61] We assume that the costs are equal for both parties. Given that the road users are of a different type, one could argue that their costs differ, $c_i \neq c_j$.This would not affect the qualitative results of the analysis, except in the case where the difference between the costs is so high that a corner solution – only one party has to take care and adapt his activity – is socially optimal. If it is socially optimal that only the car driver takes care and adapts his activity, strict liability leads to the socially optimal solution. If on the other hand only the cyclist should take care, strict liability provides the worst incentive possible.

in a decreasing way in both wealth and activity, $\frac{\partial U_k}{\partial w_k} > 0, \frac{\partial^2 U_k}{\partial w_k^2} < 0, \frac{\partial U_k}{\partial ac_k} > 0, \frac{\partial^2 U_k}{\partial ac_k^2} < 0$ ***(a6)***; that the utility for a given wealth and activity level is always larger if not involved in an accident, $U_k\left(w_k, ac_k, 0\right) \geq U_k\left(w_k, ac_k, 1\right), \forall w_k, ac_k$ ***(a7)*** and that the marginal utility of income is lower or equal when injured than if not, $\frac{\partial U_k\left(w_k, ac_k, 0\right)}{\partial w_k} \geq \frac{\partial U_k\left(w_k, ac_k, 1\right)}{\partial w_k}$ ***(a8)***. This is corroborated by Viscusi et al. (1990) who indeed find that a physical injury lowers the victims' marginal utility of income.

For accidents between a car and a cyclist we state that no matter who is responsible, the cyclist usually suffers more. We assume that in this type of accidents, the car driver only has pecuniary damage, $pl_i > 0, npl_i = 0$. The cyclist suffers both pecuniary and non pecuniary damages, $pl_j > 0, npl_j > 0$ ***(a9)***. This means that the utility for a given wealth and activity, the marginal utility of income and the marginal utility of activity of the car driver is not affected by the occurance of an accident, $U_{i|q=0} = U_{i|q=1}, \frac{\partial U_{i|q=0}}{\partial w_i} = \frac{\partial U_{i|q=1}}{\partial w_i}, \frac{\partial U_{i|q=0}}{\partial ac_i} = \frac{\partial U_{i|q=1}}{\partial ac_i}$ ***(a10)***. On the other hand, because of the personal injury, the utility, the marginal utility of income and the marginal utility of activity decrease when the cyclist is involved in an accident, $U_{j|q=0} > U_{j|q=1}, \frac{\partial U_{j|q=0}}{\partial w_j} > \frac{\partial U_{j|q=1}}{\partial w_j}, \frac{\partial U_{j|q=0}}{\partial ac_j} > \frac{\partial U_{j|q=1}}{\partial ac_j}$ ***(a11)***.

As a reference we first discuss the case in which the government does not intervene – i.e. the private optimum. Next, we discuss the social optimum and the different liability rules.

3.1. Private optimum - No Liability

If the government does not intervene, there is in fact a 'no liability' rule and each party bears his/her own losses. This implies that the private optimal care and activity under no liability, x_k^{nl} and ac_k^{nl} are determined by optimising equation (1), which represents the individual utility under a no liability rule IW_k^{nl}, with respect to x_k and ac_k.

$$IW_k^{nl} = \left(1-p\right)U_k\left(w_0 - ac_k x_k, 0\right) + pU_k\left(w_0 - ac_k x_k - pl_k - npl_k, 1\right) \tag{1}$$

<u>*(a).*</u> <u>*Care*</u>

The level of care exerted by the car driver is determined by expression (2):

$$\frac{\partial IW_i^{nl}}{\partial x_i} = -p_{x_i} U_{i|q=0} + (1-p)\frac{\partial U_{i|q=0}}{\partial w_i}(-ac_i) + p_{x_i} U_{i|q=1} + p\frac{\partial U_{i|q=1}}{\partial w_i}(-ac_i) = 0$$
$$\Leftrightarrow \underbrace{\left[(1-p)\frac{\partial U_{i|q=0}}{\partial w_i} + p\frac{\partial U_{i|q=1}}{\partial w_i}\right]\cdot 1\cdot(ac_i)}_{MC\ Care} = \underbrace{p_{x_i}\left[U_{i|q=1} - U_{i|q=0}\right]}_{MB\ Care} \qquad (2)$$

The car driver takes care as long as the marginal cost of taking care equals his marginal benefit. The marginal cost of taking care is one[62] times the activity level, weighted at his expected marginal utility of income. Hence the level of care will depend on the activity level. The marginal utility of income of the car driver for a given wealth is not directly affected because he has no personal injuries (cf. *a10*). However, the accident does change the marginal utility as wealth decreases due to the pecuniary losses (cf. *a6*). The marginal benefit of taking care equals the change in probability of an accident when he takes more care multiplied with the difference in utility between having an accident and not. If there is no liability, the car driver only takes into account the effect of his level of care on his accident costs and hence on his utility. He does not take into account the beneficial effect of his care on the expected loss in utility for the cyclist if an accident happens.

For the cyclist we find a similar result in equation (3). Under no liability he does not take into account the benefits for the car driver of his level of care.

$$\frac{\partial IW_j^{nl}}{\partial x_j} = -p_{xj} U_{j|q=0} + (1-p)\frac{\partial U_{j|q=0}}{\partial w_j}(-ac_j) + p_{x_j} U_{j|q=1} + p\frac{\partial U_{j|q=1}}{\partial w_j}(-ac_j) = 0$$
$$\Leftrightarrow \underbrace{\left[(1-p)\frac{\partial U_{j|q=0}}{\partial w_j} + p\frac{\partial U_{j|q=1}}{\partial w_j}\right]\cdot 1\cdot(ac_j)}_{MC\ Care} = \underbrace{p_{x_j}\left[U_{j|q=1} - U_{j|q=0}\right]}_{MB\ Care} \qquad (3)$$

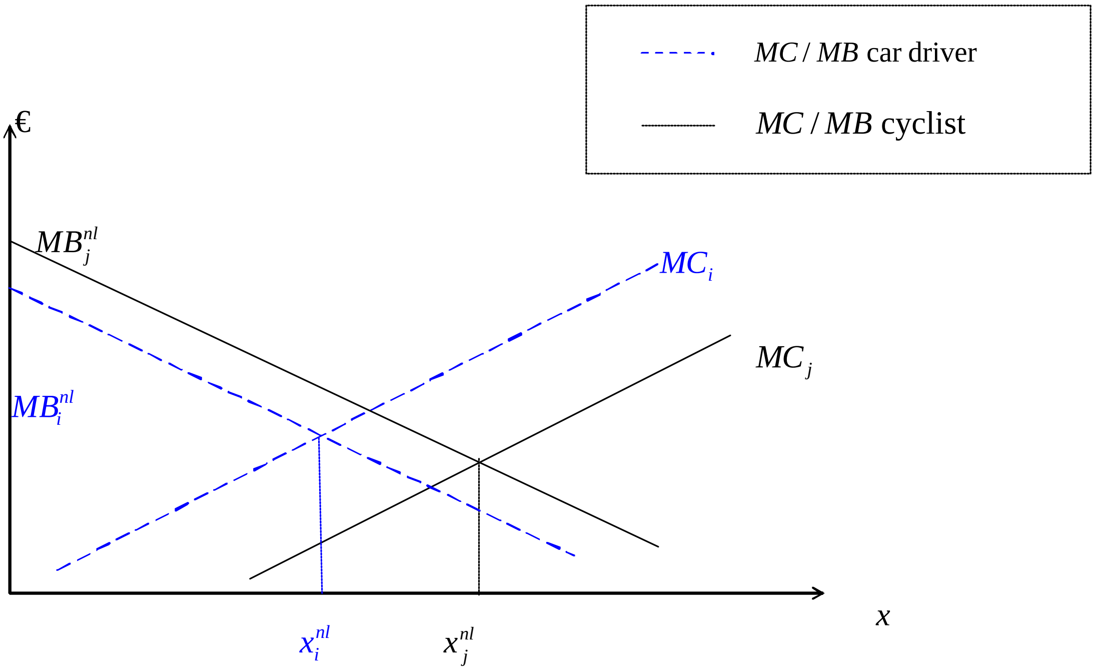
Even though the costs of care are the same, this is, equal to one, we cannot say who takes more care. On the one hand, the marginal benefit of taking care is higher and the marginal cost is lower for the cyclist. This is because the difference in utility between being injured or not is higher because they risk life and limbs and the car drivers not, ($U_{i|q=1} - U_{i|q=0} < U_{j|q=1} - U_{j|q=0}$ (cf. *a10* and *a11*)) and because the marginal utility when not involved in an accident is the same and the marginal utility when involved in an accident is

---

[62] Remember that we normalised the cost of taking care to 1 (cf. *a4*).

larger for the car driver then for the cyclist[63], $\frac{\partial U_{i|q=0}}{\partial w_i} = \frac{\partial U_{j|q=0}}{\partial w_j}$ and $\frac{\partial U_{i|q=1}}{\partial w_i} > \frac{\partial U_{j|q=1}}{\partial w_j}$. On the other hand, the marginal cost is multiplied by the activity level. If the cyclists drives more, $ac_j^{nl} > ac_i^{nl}$ we cannot say who takes more care. If the car driver has the highest activity level, $ac_i^{nl} > ac_j^{nl}$ the cyclist takes more care. We show this case in Figure 4. 1[64]. On the horizontal axis, we find the level of care and on the vertical axis we find the marginal benefits and costs, expressed in euro. The marginal benefit of taking care decreases with the level of care; the marginal cost increases. The dotted curves show the marginal cost and benefit for the car driver while the full lines represent the cyclist. The private optimal level of care x_k^{nl} is found at the intersection of the marginal cost and benefit curves. We see immediately that $x_i^{nl} < x_j^{nl}$ in this case. The car driver is less inclined to take care than the cyclist.

Figure 4. 1: Levels of care under no liability



---

[63] $\frac{\partial U_{i|q=1}}{\partial w_i} = \frac{\partial U_{|q=0}}{\partial w_i} = \frac{\partial U_{j|q=0}}{\partial w_j} > \frac{\partial U_{j|q=1}}{\partial w_j}$ (cf. *a5* and *a11*)

[64] Note that the curves do not have to be linear. This merely simplifies the graphical representation.

We cannot say that this is always the case. We first have to analyse the activity level. Moreover, the real question is: will he take socially optimal care?

(b). Activity level

Expression (4) gives the optimality condition for the activity level of the car driver in the private optimum.

$$\frac{\partial IW_i^{nl}}{\partial ac_i} = -p_{ac_i} U_{i|q=0} + (1-p)\left[\frac{\partial U_{i|q=0}}{\partial w_i}(-x_i) + \frac{\partial U_{i|q=0}}{\partial ac_i}\right] + p_{ac_i} U_{i|q=1} + p\left[\frac{\partial U_{i|q=1}}{\partial w_i}(-x_i) + \frac{\partial U_{i|q=1}}{\partial ac_i}\right] = 0$$

$$\Leftrightarrow \underbrace{\left(\frac{\partial U_{i|q=0}}{\partial ac_i}\right)}_{MB\ activity} = \underbrace{p_{ac_i}\left[U_{i|q=1} - U_{i|q=0}\right] + 1 \cdot x_i\left[(1-p)\frac{\partial U_{i|q=0}}{\partial w_i} + p\frac{\partial U_{i|q=1}}{\partial w_i}\right]}_{MC\ Activity} \tag{4}$$

We find that the private optimal activity level s_i^{nl} is determined where the benefit of making an additional trip equals the marginal costs. The marginal costs equal the sum of the increase in expected own accident costs due to the extra trip and the cost of taking care during this additional trip. Hence, the activity level depends on the level of care. Note that the car driver does not take into account the effect of his additional driving on the utility of the cyclist. We determine later that this is not socially optimal. Equation (5) shows the similar expression for the cyclist.

$$\frac{\partial IW_j^{nl}}{\partial ac_j} = -p_{ac_j} U_{j|q=0} + (1-p)\left[\frac{\partial U_{j|q=0}}{\partial w_j}(-x_j) + \frac{\partial U_{j|q=0}}{\partial ac_j}\right] + p_{ac_j} U_{j|q=1} + p\left[\frac{\partial U_{j|q=1}}{\partial w_j}(-x_j) + \frac{\partial U_{j|q=1}}{\partial ac_j}\right] = 0$$

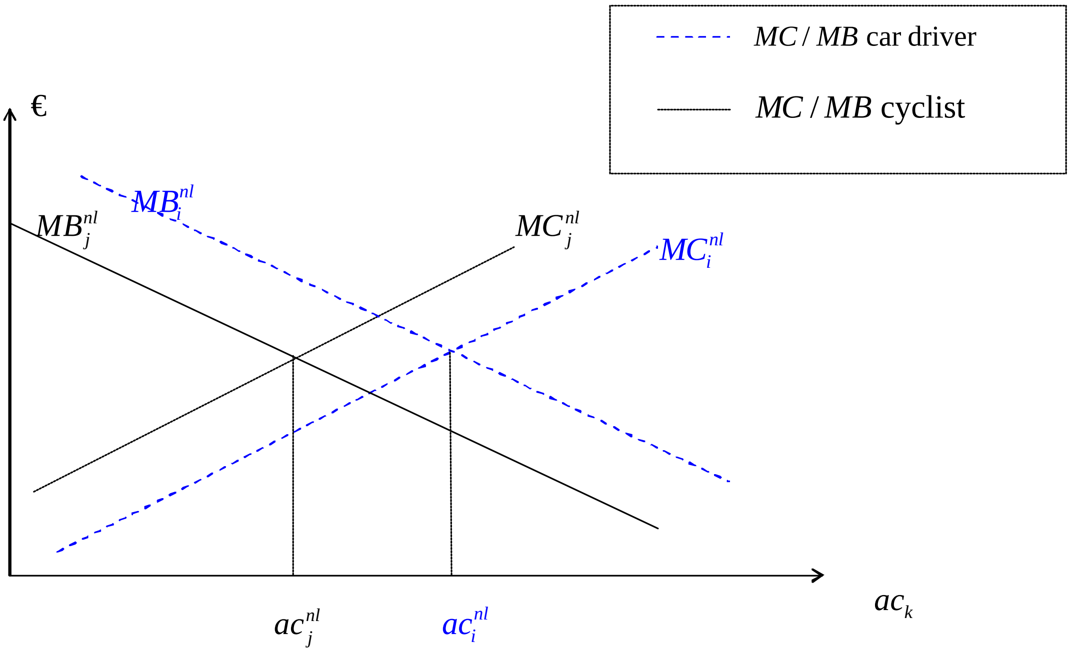
$$\Leftrightarrow \underbrace{(1-p)\left(\frac{\partial U_{j|q=0}}{\partial ac_j}\right) + p\left(\frac{\partial U_{j|q=1}}{\partial ac_j}\right)}_{MB\ activity} = \underbrace{p_{ac_j}\left[U_{j|q=1} - U_{j|q=0}\right] + 1 \cdot x_j\left[(1-p)\frac{\partial U_{j|q=0}}{\partial w_j} + p\frac{\partial U_{j|q=1}}{\partial w_j}\right]}_{MC\ Activity} \tag{5}$$

As a case in point, the marginal benefit of making a trip is lower for the cyclist than for the car driver (cf. *a10* and *a11*). We cannot be sure whose marginal cost is the largest. On the one hand, the difference in utility is higher for the cyclist then for the car driver. On the other hand, the cost of taking care per unit of care is lower for the cyclist because of the decreased marginal utility of income (cf. *a10* and *a11*). Given that we cannot determine the relation between the activity levels, we cannot say whose level of care will be the highest.

Figure 4. 2 shows the level of activity under no liability, given the level of care, x_k^{nl}, for road user k. The vertical axis again represents the marginal cost and benefit in euro; the horizontal axis shows the activity level. We show the case where the marginal cost of driving is higher for the cyclist and $x_i^{nl} < x_j^{nl}$. This is, the difference in utility and his higher level of care

outweighs the lower cost of taking care. The activity level is then lower for the cyclist than for the car driver. If the marginal cost of driving is lower for the cyclist we cannot say who takes the most care, nor who takes the most trips. For that reason we focus in the remainder of the text on the relationship of the levels of care and activity under the different liability rules with the social optimum. In order to ease the comparison between the figures, we illustrate only the clear-cut case, this is, where the marginal cost of taking care is lower and the marginal cost of activity is higher for the cyclists then for the car driver.

Figure 4. 2: Level of activity under no liability



Now that we know the private optimum, we determine the social optimum and compare the two.

3.2. Social optimum

We assume that expected social welfare equals the sum[65] of the utilities when no accident happens and the utilities when an accident happens ***(a12)***.

---

[65] This implicitly assumes that there are as many cyclists as car drivers. If there are less cyclists (car drivers), the social optimum is closer to the private optimum of the car driver (cyclist) and the externality problem is smaller for the car driver (cyclist). It might therefore be better to choose the rule which gives the best incentives to the cyclist (car users).

$$SWF = (1-p)\sum_k \left[U_k\left(w_0 - ac_k x_k, 0\right)\right] + p\sum_k\left[U_k\left(w_0 - ac_k x_k - pl_k - npl_k, 1\right)\right] \qquad (6)$$

With $k = i, j$.

(a). Care

We find the socially optimal level of care for the car driver by maximising (6) with respect to his level of care, x_i.

$$\begin{aligned}
\frac{dSWF}{dx_i} &= (1-p)\frac{\partial U_{i|q=0}}{\partial w}(-ac_i) + \left(-p_{x_i}\right)\left(\sum_k\left[U_k\left(w_0 - ac_k x_k, 0\right)\right]\right) \\
&+ p\frac{\partial U_{i|q=1}}{\partial w}(-ac_i) + \left(p_{x_i}\right)\left(\sum_k\left[U_k\left(w_0 - ac_k x_k - pl_k - npl_k, 1\right)\right]\right) = 0 \qquad (7) \\
&\Leftrightarrow \left((1-p)\frac{\partial U_{i|q=0}}{\partial w} + p\frac{\partial U_{i|q=1}}{\partial w}\right)ac_i = p_{x_i}\left(U_{i|q=1} - U_{i|q=0} + U_{j|q=1} - U_{j|q=0}\right)
\end{aligned}$$

This means that at the socially optimal level of care, the marginal cost equals the total marginal benefit of taking care. The marginal cost of taking care is $ac_k \cdot 1$, corrected for the expected marginal utility of income. The benefit of taking one more unit of care equals the reduction in expected accident risk times the loss in utility caused by an accident for both parties. In the social optimum, the effect on the cyclist is also taken into account. This makes the benefit of taking care higher and consequently the level of care in the social optimum is higher than in the private optimum.

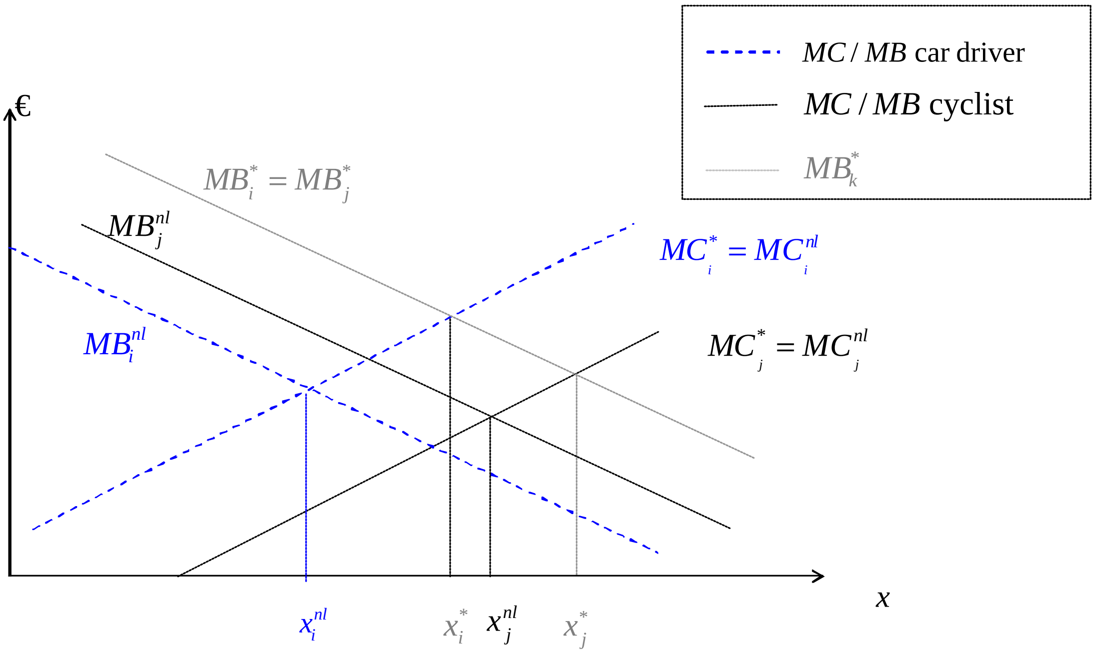
The socially optimal level of care for the cyclist is determined by an expression identical to equation (7). The cyclist should also choose his care level such that his marginal cost equals the total marginal benefit. The marginal benefit is the same for both users since we assume that both affect the probability of an accident in the same way, $p_{x_i} = p_{x_j}$ (cf. *a3*)[66]. Taking into account that the level of care affects both road users, makes it socially optimal for the cyclist to take more care than in the private optimum. We show in Figure 4. 3 the case where the marginal cost is lower for the cyclist. This figure has the same structure as Figure 4. 1. We again show the case of no liability, denoted in black and compare with the social

---

[66] Even if $p_{x_i} > p_{x_j}$ or $p_{x_j} > p_{x_i}$ the result stays that both take more care than in the private optimum because the marginal benefit of taking care is higher under the social optimum. This assumption only affects the difference in care level between both road users.

optimum, denoted in grey. The marginal benefit under the social optimum is the same for both users and is higher than under no liability because it takes into account the effect on utility for both road users. The marginal cost curves stay the same as in the no liability case. Hence $x_k^{nl} < x_k^*, k = i, j$.

Figure 4. 3: Socially optimal level of care



(b). Activity level

The socially optimal activity level is found in a similar way. From equation (8) we derive that for the car driver and the cyclist the socially optimal activity level is determined by the point where the benefit equals the cost of making an additional trip.

$$\frac{\partial SWF}{\partial ac_k} = (1-p)\left[\frac{\partial U_{k|q=0}}{\partial w_k}(-x_k) + \frac{\partial U_{k|q=0}}{\partial ac_k}\right] + \left[\sum_k U_{k|q=0}\right](-p_{ac_k})$$

$$+p\left[\frac{\partial U_{k|q=1}}{\partial w_k}(-x_k) + \frac{\partial U_{k|q=1}}{\partial ac_k}\right] + \left[\sum_k U_{k|q=1}\right](p_{ac_k}) = 0$$

$$\Leftrightarrow \left[(1-p)\frac{\partial U_{k|q=0}}{\partial w_k}(-x_k) + p\frac{\partial U_{k|q=1}}{\partial w_k}(-x_k) + (1-p)\frac{\partial U_{k|q=0}}{\partial ac_k} + p\frac{\partial U_{k|q=1}}{\partial ac_k}\right]$$

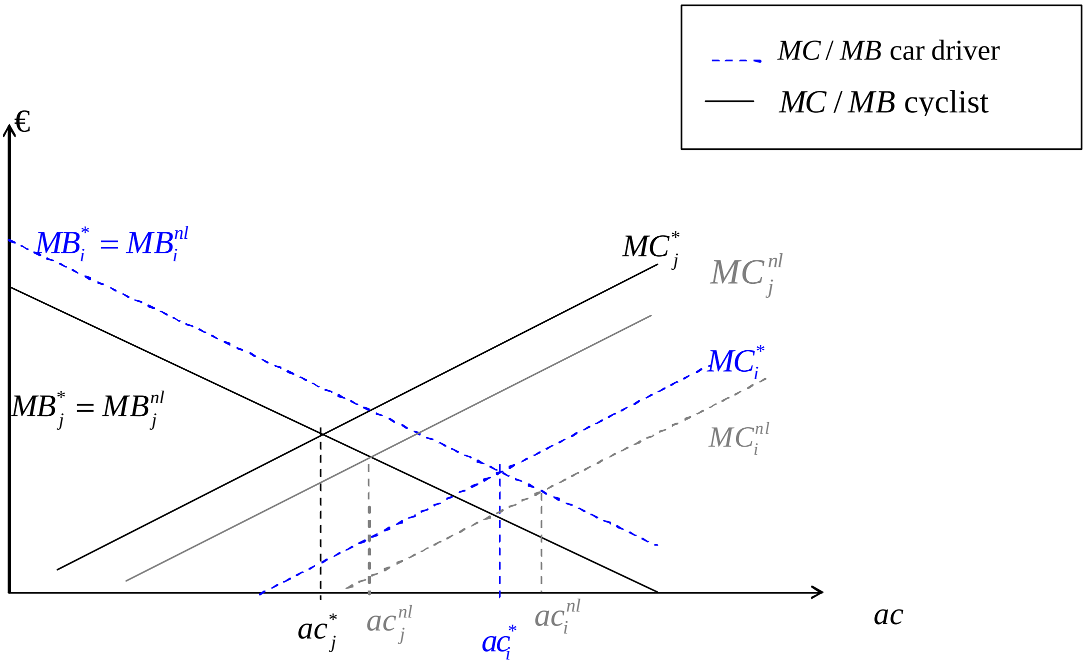
$$= (p_{ac_k})\left[U_{i|q=1} - U_{i|q=0} + U_{j|q=1} - U_{j|q=0}\right]$$

$$\Leftrightarrow (1-p)\frac{\partial U_{k|q=0}}{\partial ac_k} + p\frac{\partial U_{k|q=1}}{\partial ac_k} = (p_{ac_k})\left[U_{i|q=1} - U_{i|q=0} + U_{j|q=1} - U_{j|q=0}\right] + x_k\left[(1-p)\frac{\partial U_{k|q=0}}{\partial w_k} + p\frac{\partial U_{k|q=1}}{\partial w_k}\right]$$

(8)

The marginal social benefit equals the increase in expected utility from taking an additional trip and is the same as under the private optimum. The marginal costs consist of two elements. The first represents the expected accident cost of taking an additional trip. Given the assumption that the activity level influences the probability of an accident in the same way, $p_{ac_i} = p_{ac_j}$ (cf. *a3*), this part is the same for both road users under the social optimum and larger than the corresponding part in the private optimum. The second element of the marginal costs is the cost of taking care. This is the same as in the no liability case. The cost per unit of care is lower for the cyclist than for the car driver, but the cyclist can take more care. Hence we cannot be sure whose marginal cost is the highest. Hence we cannot determine whose socially optimal activity level is the lowest. Compared with the private optimum, the socially optimal activity levels will be lower since the marginal costs are higher, $ac_k^* < ac_k^{nl}, k = i, j$. We show the case where the social marginal benefits and the costs for the cyclist are lower than for the car driver and therefore the socially optimal activity level of the cyclist is lower than of the car driver, $ac_j^* < ac_i^*$, in Figure 4. 4.

Figure 4. 4: Socially optimal activity levels



Hence, to summarise, the socially optimal level of care is higher and the socially optimal activity level is lower than the private optimum. For in the social optimum the influence of the level of care and the level of activity on both parties is taken into account while in the private optimum only the effect on the own utility is taken into account. This is the classic externality problem. We now investigate if, and how, liability rules solve this externality.

4. INFLUENCE OF LIABILITY RULES

In this paragraph we discuss the effect of three different liability rules. First, we discuss strict liability - the rule actually in use in many countries for this type of accidents - and compare it with the rules usually used for accidents between cars - these are negligence and comparative negligence.

4.1. Strict liability

Under strict liability the car driver is always liable whatever his level of care and whatever the behaviour of the cyclist. Hence, he has to pay for the losses of the cyclist, but is not compensated for his own loss. The cyclists' monetary losses are compensated, but due to the personal injuries his marginal utility of income and activity decreases. The individual utility functions then take the form as in equation (9) and (10).

$$IW_i^{sl} = (1-p)U_i\left(w_0 - ac_i x_i, ac_i, 0\right) + pU_i\left(w_0 - ac_i x_i - pl_i - pl_j - npl_j, ac_i, 1\right) \tag{9}$$

$$IW_j^{sl} = (1-p)U_j\left(w_0 - ac_j x_j, ac_j, 0\right) + pU_j\left(w_0 - ac_j x_j + 0, ac_j, 1\right) \tag{10}$$

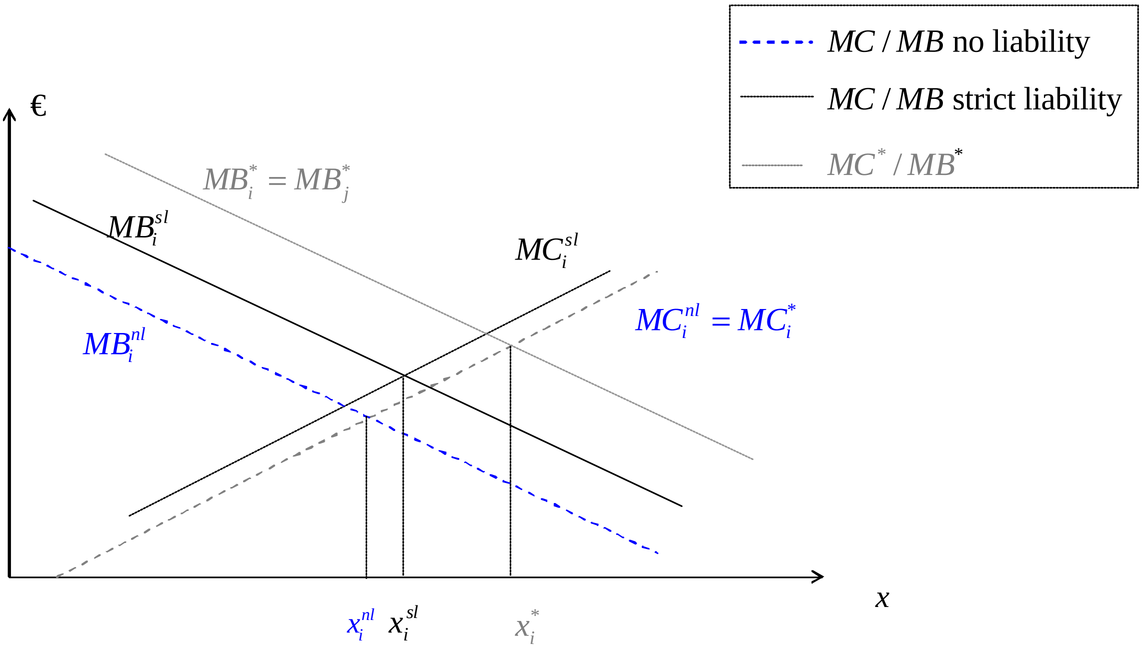
(a). Care

For the car driver we obtain equation (11). This is similar to equation (2) – the no liability case- because it does not take into account the effect on the utility of the cyclist. However the marginal benefit of taking care is larger because the difference in utility at the right-hand side is larger because the car driver has to pay more than under no liability.

$$\begin{aligned} &U_i\left(w_0 - ac_i x_i - pl_i - pl_j - npl_j, ac_i, 1\right) - U_i\left(w_0 - ac_i x_i, ac_i, 0\right) \\ &> U_i\left(w_0 - ac_i x_i - pl_i, ac_i, 1\right) - U_i\left(w_0 - ac_i x_i, ac_i, 0\right) \end{aligned} \tag{11}$$

The marginal cost curve increases slightly because there is also an effect on the marginal utility of income due to the changes in wealth (cf. *a6*). Thus he exerts more care than in the no liability case. However, he still takes less care than socially optimal because he does not take into account the effect on the utility of the cyclist. We show the socially $\left(x_i^*\right)$ and privately $\left(x_i^{nl}\right)$ optimal level of care and the level of care chosen under strict liability $\left(x_i^{sl}\right)$ in Figure 4. 5. We see that $x_i^{nl} < x_i^{sl} < x_i^*$. In theory, the car driver could take more care under no liability than under strict liability if the wealth effect on marginal utility is large. However, he will never exert socially optimal care.

Figure 4. 5: Care of the car driver under strict liability

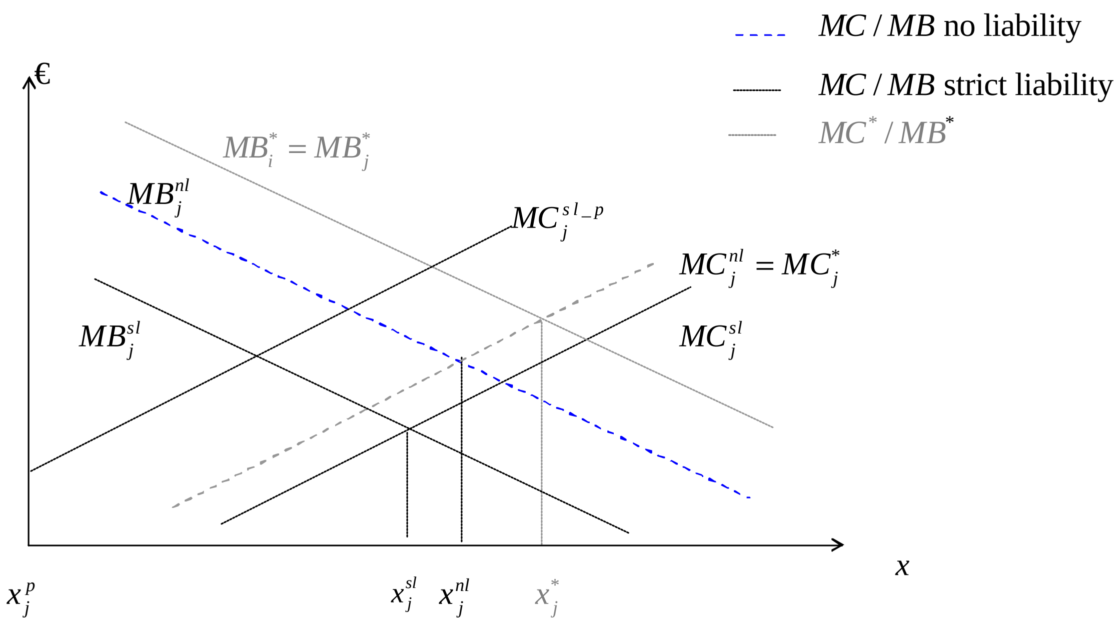


For the cyclist we find an expression similar to equation (3). The marginal benefit of taking care is smaller because the difference in utility is smaller under strict liability than under no liability, because his monetary losses are compensated.

$$\begin{aligned} &U_j\left(w_0 - ac_j x_j + 0, ac_j, 1\right) - U_j\left(w_0 - ac_j x_j, ac_j, 0\right) \\ &> U_j\left(w_0 - ac_j x_j - pl_j - npl_j, ac_j, 1\right) - U_j\left(w_0 - ac_j x_j, ac_j, 0\right) \end{aligned} \tag{12}$$

The fact that the cyclist is partly compensated makes that the marginal cost of taking care is lower under strict liability then under no liability because the wealth effect on the marginal utility of income is lower. Hence, he takes less care than under no liability, $x_j^{nl} > x_j^{sl}$. However, he takes some care due to the non-pecuniary losses, although less than socially optimal, $x_j^{sl} < x_j^*$. We explain this using Figure 4. 6. Under strict liability, the marginal cost of taking care is lower than in the social optimum. The marginal benefit is lower under strict liability than under no liability because under strict liability, the cyclist is partly compensated. The marginal benefit under no liability is on its turn lower than the social marginal benefit.

Figure 4. 6: Level of care under strict liability



Under strict liability, the cyclist takes less care than under no liability because he is partly compensated, $x_j^{sl} < x_j^{nl} < x_j^*$. If his utility would not be affected by an accident or if the car driver also has to compensate the utility loss, equation (3) changes into

$$MC_j^{sl-p} = \frac{\partial U_{j|q=0}}{\partial w_j} ac_j = 0 \qquad (13)$$

He then simply minimizes the cost of taking care and takes no care[67] at all, $x_j^p = 0$. Hence, there lies truth in the argument that the cyclist takes care even if he is not liable[68] because he risks life and limbs.

---

[67] This depends on the shape of the marginal cost of taking care. It is possible that he will take some care as long as the marginal cost of doing this equals zero.

[68] However, the social optimum if his utility is affected (x_j^*) is higher than the social optimum if his utility is not affected (intersection of MC_j^{sl-p} and MB_j^*).

(b). Activity level

The activity level of the car driver is determined by an equation like (4). Because the difference in utility under strict liability is higher than under no liability, the marginal cost curves increase and, hence, the activity level decreases. However, he does not take into account the effect on the utility of the cyclist and, hence, the activity under strict liability is higher than socially optimal, $ac_i^* < ac_i^{sl} < ac_i^{nl}$. For the cyclist the activity level is determined as in equation (5). Given that he is compensated, the difference in utility is smaller and, hence, his activity level higher than the socially optimal level and the level under no liability, $ac_j^* < ac_j^{nl} < ac_j^{sl}$.

The question we want to answer is if it is necessary to have a different rule for accidents between cars and accident between cars and cyclists. Hence we now examine the effect of a negligence rule on the behaviour of the road users.

4.2. Negligence

The behaviour under a negligence rule is less clear cut. The road users take into account the decision of the other players. We assume that the due level of care is set to the optimal second best level. Remember that this socially optimal care depends on the activity level. In setting the due level of care, the social planner takes into account that under a rule of negligence he cannot directly influence the activity level. Given the relationship between the private optimal level and the socially optimal level, the activity level if one cannot influence the activity level directly will be higher than socially optimal. This does not mean that the level of due care should be higher than the socially optimal level of care when the activity level can be influenced since a higher activity level both increases the marginal cost and benefit of taking care. Note that the exact level of this second best level of care is not imperative. Important is to which extend the liability rule is able to reach this level.

For the analysis we use the following notation. p^{--} stands for the probability of an accident if both road users take less than due care. p^{-*} and p^{*-} represent the probability of an accident if one of the road users takes due care and the other takes less than due care. p^{**} stands for the accident probability if both take due care.

$$\begin{aligned} p^{--} &= p\left(x_i^-, x_j^-, ac_i, ac_j\right) \qquad p^{-*} = p\left(x_i^-, x_j^*, ac_i, ac_j\right) \\ p^{*-} &= p\left(x_i^*, x_j^-, ac_i, ac_j\right) \qquad p^{**} = p\left(x_i^*, x_j^*, ac_i, ac_j\right) \end{aligned} \tag{14}$$

Under a simple negligence rule, the following game appears. Each cell first gives the expected utility for the car driver and then the expected utility for the cyclist given the four different possible combinations of the level of care. The first row gives the expected utility for the road users if the cyclist takes less than due care. The second row gives the utilities when the cyclist takes at least due care. The first column gives the utilities if the car driver takes less than due care, while the second column shows the case where he takes at least due care.

Car Cyclist	$x_i < x_i^*$	$x_i \geq x_i^*$
$x_j < x_j^*$	$\left(1-p^{--}\right)U_i\left(w_0 - ac_i x_i^-, ac_i, 0\right) + p^{--}U_i\left(w_0 - ac_i x_i^- - pl_j - npl_j, ac_i, 1\right)$ $\left(1-p^{--}\right)U_j\left(w_0 - ac_j x_j^-, ac_j, 0\right) + p^{--}U_j\left(w_0 - ac_j x_j^- - pl_i, ac_j, 1\right)$	$\left(1-p^{*-}\right)U_i\left(w_0 - ac_i x_i^*, ac_i, 0\right) + p^{*-}U_i\left(w_0 - ac_i x_i^*, ac_i, 1\right)$ $\left(1-p^{*-}\right)U_j\left(w_0 - ac_j x_j^-, ac_j, 0\right) + p^{*-}U_j\left(w_0 - ac_j x_j^- - pl_j - npl_j - pl_i, ac_j, 1\right)$
$x_j \geq x_j^*$	$\left(1-p^{-*}\right)U_i\left(w_0 - ac_i x_i^-, ac_i, 0\right) + p^{-*}U_i\left(w_0 - ac_i x_i^- - pl_i - pl_j - npl_j, ac_i, 1\right)$ $\left(1-p^{-*}\right)U_j\left(w_0 - ac_j x_j^*, ac_j, 0\right) + p^{-*}U_j\left(w_0 - ac_j x_j^*, ac_j, 1\right)$	$\left(1-p^{**}\right)U_i\left(w_0 - ac_i x_i^*, ac_i, 0\right) + p^{**}U_i\left(w_0 - ac_i x_i^* - pl_i, ac_i, 1\right)$ $\left(1-p^{**}\right)U_j\left(w_0 - ac_j x_j^*, ac_j, 0\right) + p^{**}U_j\left(w_0 - ac_j x_j^* - pl_j - npl_j, ac_j, 1\right)$

(a). Care

We can proof[69] that under the following conditions the solution that all road users take due care $\left(x_i^*, x_j^*\right)$ is a Nash equilibrium. The car driver takes due care, whatever the behaviour of the cyclist, if

---

[69] See appendix 4A

$$\left(a_i\right)\ ac_i x_i^* < ac_i x_i^- + pl_i + pl_j + npl_j$$

and

$$\left(b_i\right)\ p^{--} > p_1$$

with $p_1 : U\left(w_0 - ac_i x_i^*, ac_i, 0\right) =$

$$(1-p_1)U\left(w_0 - ac_i x_i^-, ac_i, 0\right) + p_1 U\left(w_0 - ac_i x_i^- - pl_j - npl_j, ac_i, 1\right) \tag{15}$$

and

$$\left(c_i\right)\ p^{-*} > p_2$$

with $p_2 :\ U\left(w_0 - ac_i x_i^* - pl_i, ac_i, 0\right) =$

$$(1-p_2)U\left(w_0 - ac_i x_i^-, ac_i, 0\right) + p_2 U\left(w_0 - ac_i x_i^- - pl_j - npl_j, ac_i, 1\right)$$

The first condition $\left(a_i\right)$ states that the total costs of taking due care should be smaller than taking less than due care and paying for all the accident costs. The last two conditions, $\left(b_i\right)$ and $\left(c_i\right)$, state that the probability of having an accident if the car driver does not take due care - taking into account the possible behaviour of the cyclist - should be larger than the probability which equates the expected utility when taking less than due care to the utility of taking due care and having no accident (certainty equivalent). This is, if the probability of an accident when taking less then due care is very low, it is not worthwhile paying for due care.

Cyclists take due care, whatever the behaviour of the car driver if

$$\left(a_j\right)\ ac_j x_j^* < ac_j x_j^- + pl_i$$

and

$$\left(b_j\right)\ p^{--} > p_3$$

with $p_3 : U\left(w_0 - ac_j x_j^*, ac_j, 1\right) =$

$$(1-p_3)U\left(w_0 - ac_j x_j^-, ac_j, 0\right) + p_3 U\left(w_0 - ac_j x_j^- - pl_i, ac_j, 1\right) \tag{16}$$

and

$$\left(c_j\right)\ p^{-*} > p_4$$

with $p_4 :\ U\left(w_0 - ac_j x_j^*, ac_j, 1\right) =$

$$(1-p_4)U\left(w_0 - ac_j x_j^-, ac_j, 0\right) + p_4 U\left(w_0 - ac_j x_j^- - pl_i - pl_j - npl_j, ac_j, 1\right)$$

The first condition $\left(a_j\right)$ again states that the total costs of taking due care should be smaller than taking less than due care and paying for the accident losses of the other party involved. Condition $\left(b_j\right)$ says that the probability of an accident if both take less than due care should be larger than the probability which equates the utility if the cyclist takes due care and an accident occurs to the expected utility if he takes less than due care. If the probability is smaller, the cyclist would be better of taking less than due care even if the car driver also takes less than due care. The third condition $\left(c_j\right)$ says that the probability when only the car driver takes due care should be high enough to induce the cyclist to take also due care.

If conditions (15) and (16) are satisfied[70], we can be certain that the equilibrium where both road users take due care is a Nash equilibrium. It is possible that even if they are not satisfied that both take due care. This depends on the shape of the utility function and the magnitude of the losses.

Note that if the court or the social planner makes random errors in setting due care or in comparing actual care with due care or if the injurer makes random errors in predicting the due level of care this creates uncertainty. Raising the care level then costs relatively little and drivers will increase their level of care to avoid being held liable (Shavell, 2004). If the level of due care is set too low – this is lower than the second best – the drivers will more easily comply and they will comply with this level and hence exercise suboptimal care. If the due care is set too high, the drivers will be less inclined to comply and if they comply, their level of care is higher than optimal. Moreover, the level of care can be defined over different dimensions (level of speed, complying with other traffic regulation, etc.). If the due care does not cover all these dimensions, the drivers will only comply with the dimensions covered (Shavell, 1987; Cooter and Ulen, 2004).

(b). Activity level

For each of the four situations $\left[\left(x_i^*,x_j^*\right),\left(x_i^*,x_j^-\right),\left(x_i^-,x_j^*\right),\left(x_i^-,x_j^-\right)\right]$ the matrix above shows the expected utility that the road user will maximise when he determines his activity level. There is no situation in which the road user takes into account the effect of his driving on the utility of the other road user, while the social optimum does (compare with for example (8)). Hence the activity level is never socially optimal under negligence. They both drive too much, $ac_k^n > ac_k^*$. The social planner can take this – to some extend- into account in setting

---

[70] Note that if $\left(b_j\right)$ is satisfied, $\left(b_i\right)$ is also satisfied.

the due level of care. The socially optimal level of activity s_k^* can, however, never be reached under a pure negligence rule.

4.3. *Comparative Negligence*

The only difference between comparative negligence and negligence is the case where both take less than due care. Under negligence, each party bears the cost he causes; hence the car driver pays the cost of the cyclist and vice versa. Under comparative negligence, each party bears a fraction l of the total costs, where the fraction is determined by a comparison of the amount by which the two parties' levels of care depart from the due levels of care.

Under comparative negligence the matrix then looks at follows:

Car Cyclist	$x_i < x_i^*$	$x_i \geq x_i^*$
$x_j < x_j^*$	$\left(1-p^{--}\right)U_i\left(w_0 - ac_i x_i^-, ac_i, 0\right)+$ $p^{--}U_i\left(w_0 - ac_i x_i^- - l\left(pl_i + pl_j + npl_j\right), ac_i, 1\right)$ $\left(1-p^{--}\right)U_j\left(w_0 - ac_j x_j^-, ac_j, 0\right)+$ $p^{--}U_j\left(w_0 - ac_j x_j^- - (1-l)\left(pl_i + pl_j + npl_j\right), ac_j, 1\right)$	$\left(1-p^{*-}\right)U_i\left(w_0 - ac_i x_i^*, ac_i, 0\right)+$ $p^{*-}U_i\left(w_0 - ac_i x_i^*, ac_i, 1\right)$ $\left(1-p^{*-}\right)U_j\left(w_0 - ac_j x_j^-, ac_j, 0\right)+$ $p^{*-}U_j\left(w_0 - ac_j x_j^- - pl_j - npl_j - pl_i, ac_j, 1\right)$
$x_j \geq x_j^*$	$\left(1-p^{-*}\right)U_i\left(w_0 - ac_i x_i^-, ac_i, 0\right)+$ $p^{-*}U_i\left(w_0 - ac_i x_i^- - pl_i - pl_j - npl_j, ac_i, 1\right)$ $\left(1-p^{-*}\right)U_j\left(w_0 - ac_j x_j^*, ac_j, 0\right)+$ $p^{-*}U_j\left(w_0 - ac_j x_j^*, ac_j, 1\right)$	$\left(1-p^{**}\right)U_i\left(w_0 - ac_i x_i^*, ac_i, 0\right)+$ $p^{**}U_i\left(w_0 - ac_i x_i^* - pl_i, ac_i, 1\right)$ $\left(1-p^{**}\right)U_j\left(w_0 - ac_j x_j^*, ac_j, 0\right)+$ $p^{**}U_j\left(w_0 - ac_j x_j^* - pl_j - npl_j, ac_j, 1\right)$

Note that this is the same matrix as in the negligence case, except for the cell where both take less than due care $\left(x_i < x_i^*, x_j < x_j^*\right)$. Hence we again can find the conditions for which the road users will take optimal care. These conditions are similar[71] to the ones in the negligence case. We find that both take due care if the conditions in (17) are fulfilled.

---

[71] Conditions $\left(c_i\right)$ and $\left(c_j\right)$ are the same as in the negligence case.

$(a_i)\ ac_i x_i^* < ac_i x_i^- + l\left(pl_i + pl_j + npl_j\right)$

and

$(b_i)\ p^{--} > p_1$

with p_1: $U\left(w_0 - ac_i x_i^*, ac_i, 0\right) =$

$(1 - p_1)U\left(w_0 - ac_i x_i^-, ac_i, 0\right) + p_1 U\left(w_0 - ac_i x_i^- - l\left(pl_i + pl_j + npl_j\right), ac_i, 1\right)$

and

$(c_i)\ p^{-*} > p_2$

with p_2: $U\left(w_0 - ac_i x_i^* - pl_i, ac_i, 0\right) =$

$(1 - p_2)U\left(w_0 - ac_i x_i^-, ac_i, 0\right) + p_2 U\left(w_0 - ac_i x_i^- - pl_j - npl_j, ac_i, 1\right)$

and

$(a_j)\ ac_j x_j^* < ac_j x_j^- + (1 - l)\left(pl_i + pl_j + npl_j\right)$

and

$(b_j)\ p^{--} > p_3$

with p_3: $U\left(w_0 - ac_j x_j^*, ac_j, 1\right) =$

$(1 - p_3)U\left(w_0 - ac_j x_j^-, ac_j, 0\right) + p_3 U\left(w_0 - ac_j x_j^- - (1 - l)\left(pl_i + pl_j + npl_j\right), ac_j, 1\right)$ (17)

and

$(c_j)\ p^{-*} > p_4$

with p_4: $U\left(w_0 - ac_j x_j^*, ac_j, 1\right) =$

$(1 - p_4)U\left(w_0 - ac_j x_j^-, ac_j, 0\right) + p_4 U\left(w_0 - ac_j x_j^- - pl_i - pl_j - npl_j, ac_j, 1\right)$

Note that comparative negligence will lead more often to the socially optimal levels of care if and only if the possible liability is larger under comparative negligence than under negligence, this is, if

$$l\left(pl_i + pl_j + npl_j\right) > pl_j + npl_j$$

and (18)

$$(1 - l)\left(pl_i + pl_j + npl_j\right) > pl_i$$

However, it is obvious that the liability under comparative negligence can not be larger than under negligence for both drivers simultaneously. In addition, for the same reason as in the negligence case, the activity level will not be optimal[72]. Hence comparative negligence has nothing to add to negligence if both road users have losses, except for the additional cost related to the determination of l .

5. INSURANCE[73]

Up to now, we assumed that people are risk neutral and hence there is no need for insurance. However, in reality people are risk averse and then the distribution of risk matters. Insurances are then socially beneficial because they make that the risk is shared. Moreover, in many countries car insurance is even mandatory. Hence it is worthwhile to discuss insurance. Given the scope of the paper – the working of liability rules - we follow a descriptive rather than an analytical approach. We first briefly discuss some general problems of insurance and then consider how the introduction of insurance changes the analysis under a rule of strict liability and under (comparative) negligence.

5.1. Some general problems of introducing insurance

The existence of insurance creates some problems. Firstly, the moral hazard problem occurs because people can influence the probability of an accident by choosing their level of care and activity. This problem increases as coverage is more complete. Secondly, insurance companies do not have perfect information on the level of care and activity. Thirdly, it greatly impacts the working of the liability rules because if insured, the driver does not have to pay for his losses or his liability himself. Hence he does not take these costs into account when determining his behaviour. The care incentives then have to be provided by the insurance company. In general, the insurance company can impose a fixed amount which can not be recovered and/or use a bonus-malus system. In general a bonus-malus system is not diversified enough to induce optimal care. As for the activity level, it might be possible to influence the activity levels of drivers through the insurance policy. For instance, the premium could be linked to the number of kilometres driven in a year. Fourthly, the

---

[72] Shavell (1987) shows that if only one party has losses, comparative negligence leads to better results with respect to the activity level than pure negligence.

[73] This paragraph is partly based on the theoretical analyses of the influence of insurances in the setting of unilateral accidents of Shavell (1982, 2004), Boyer and Dionne (1987, 1989a), Arlen (1990), Posner (1998) and Dionne et al (1999).

compensation paid by the insurer to the cyclist should exceed the pecuniary losses if the marginal utility of wealth is increasing by an accident. However, this amount will generally not make hime whole. In general, the actual insurance only covers the pecuniary losses. Hence insurance is not the mean to overcome this problem. Finally, an additional real life complication is that while car insurance is often mandatory, very few cyclists are insured.

5.2. Insurance and strict liability

Under strict liability, the cyclist is compensated and the car driver is liable. If insurance is available, car drivers will purchase third-party insurance to compensate the losses of the cyclists and possibly a first-party insurance to cover their own possible losses. If the insurance company knows the level of care and activity, he can buy insurance with full coverage with a premium equal to the expected losses. This will then lead to the social optimum. If the level of care and activity is not (perfectly) known by the insurer, the coverage will be less than complete. This is not socially optimal as the car driver is still subject to some risk and he will take less care and more activity than socially optimal. It will however be a social improvement since the cyclists are not influenced given that they are (partly) compensated in the same way whether there is insurance or not and since the car drivers choose to purchase the insurance, it must be that they are better off.

5.3. Insurance and (comparative) negligence

We found that the negligence rule made that both parties take, under certain conditions, socially optimal care. Hence there are no findings of negligence and they both bear their own losses and will both buy first party insurance. If the insurer can perfectly control the level of care and activity, there will be full coverage and the social optimum is reached. If the insurer cannot observe their care and activity levels, the insurance will not cover all losses. Remark that if the negligence rule does not function perfectly, there are findings of negligence and drivers may also buy third party insurance. However, broad third-party insurance will not be purchased because the insurance premium would be too high in this case. Instead, the insurance policies will include protections against findings of negligence that are the result of factors beyond the drivers control (for example, being find negligent through error), but not for factors under the control of the drivers.

6. CONCLUSIONS AND CAVEATS

In this paper we analyse bicycle-car accidents. We started from the observation that in many European countries this type of accidents is governed by some rule of strict liability, while accidents between cars are governed by a negligence based rule. The argument made for this ruling is that, because cyclists risk life and limbs, they take care even if they are not liable and compensated. We find that there lies some truth in this argument. They take more care than if they would not risk their life. However, the incentive is not strong enough to take the socially optimal care. Under strict liability, the cyclist exerts less care than socially optimal and drives too much. Moreover, even the car driver takes less care and drives more than socially optimal because he does not take into account the effect an accident has on the utility of the cyclist. Note that in theory this can be overcome by making the car driver pay for this loss in utility. However, this is not the case in reality[74] and would make that the cyclist takes no care and hence that the argument made by policy makers does not hold anymore.

We show that, if the cost of taking due care is not too high compared to taking less than due care and paying for the losses and if the probabilities of having an accident when none or only one party takes due care are high enough, negligence and comparative negligence can lead to the socially optimal level of care. Hence, if we only consider care we see no reason to have a different rule for accidents where a vulnerable road user is involved than when there is none involved.

However, there are different possible reasons to prefer strict liability over a negligence based rule. Firstly, when we allow for differences in wealth, for example a poor cyclist and a rich car driver, it is possible that strict liability would be preferred. However, not all cyclists are poor and there are better means to redistribute income. Secondly, when the cost of taking care is relatively much lower for the car driver then for the cyclist or when it is mainly the car driver which influences the probability of an accident, strict liability would be preferred. Thirdly, it is possible that there are other than efficiency reasons to choose for strict liability.

---

[74] In Belgium courts usually use a rule of thumb to compensate for moral damages. For example, a victim who is 100% unable to work receives 20 euro/day. A person who is declared unable to work for 20% receives 20% of 20 euro and so on. Hence if injured but able to work, one will receive no moral damages. (Schoups et al, 2000)

For example, in countries where this type of ruling is in place, it is often the case that car drivers own mandatory insurances, while cyclists are in general not insured. Fourthly, under a rule of negligence the activity level is only controlled indirectly. If it is very important to control the activity and the care of the motorised driver, the rule of strict liability performs better. If we want to control the level of care and activity level of both types, the best option would be to supplement a rule of negligence with for example a km tax or with an insurance per kilometre. The introduction of insurance does not influence the analysis significantly if we assume that the expected premium equals the expected liability cost.

Finally, we do not consider the influence of the (administrative) costs of the different rules. These are the legal and other expenses born by the party such as time and effort, the emotional costs, etc. The ‘no liability rule’ comes at no costs, while the (comparative) negligence rule is more expensive than the strict liability rule per case. However there will be more cases under a strict liability than under a negligence based rule. It is also possible that high litigation costs – which may even be higher than the amounts received by victims - may refrain the victim of making claims. This lowers the expected liability and leads to a lower care level. An administrative system based on insurance may be preferred over a liability system if administrative costs are included (Shavell, 2004).

Appendix 4A: Proof conditions negligence

We first consider the behaviour of the car driver given the behaviour of the cyclist and then turn to the cyclist. We want to determine the conditions under which $\left(x_i^*, x_j^*\right)$ is the Nash equilibrium.

(1) Car driver – cyclist takes less then due care

If the cyclist takes less than due care, the car driver takes due care if and only if the expected utility is greater or equal than taking less care.

$$\begin{aligned}&\left(1-p^{*-}\right)U_i\left(w_0-ac_ix_i^*,ac_i,0\right)+p^{*-}U_i\left(w_0-ac_ix_i^*,ac_i,1\right)\\&\geq\left(1-p^{--}\right)U_i\left(w_0-ac_ix_i^-,ac_i,0\right)+p^{--}U_i\left(w_0-ac_ix_i^- -pl_j-npl_j,ac_i,1\right)\\&\Rightarrow U_i\left(w_0-ac_ix_i^*,ac_i,0\right)\geq\left(1-p^{--}\right)U_i\left(w_0-ac_ix_i^-,ac_i,0\right)+p^{--}U_i\left(w_0-ac_ix_i^- -pl_j-npl_j,ac_i,1\right)\end{aligned}\tag{19}$$

If the car driver is risk averse, we know that for (19) to hold it is necessary that the following two conditions hold.

$$\begin{aligned}&w_0-ac_ix_i^- -pl_j-npl_j\leq w_0-ac_ix_i^*\\&\Rightarrow ac_ix_i^*\leq ac_ix_i^- +pl_j+npl_j\end{aligned}\tag{20}$$

This is, the cost of taking due care should be smaller than the costs of taking less than due care and paying for the accident losses of the cyclist.

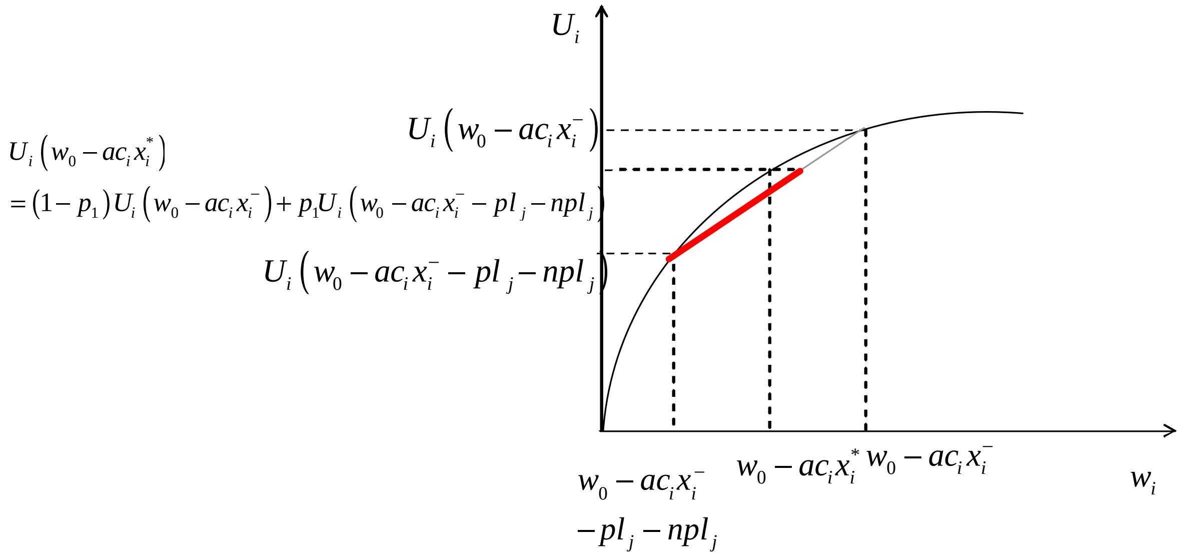
Furthermore we need that the probability of an accident when both take less than due care is larger than the probability which makes that the car driver indifferent between taking due care and taking less care given this probability.

$$\begin{aligned}&p^{--}>p_1\\&\text{with } p_1 : U_i\left(w_0-ac_ix_i^*,ac_i,0\right)=\left(1-p_1\right)U_i\left(w_0-ac_ix_i^-,ac_i,0\right)+p_1U_i\left(w_0-ac_ix_i^- -pl_j-npl_j,ac_i,0\right)\end{aligned}$$

(21)

It is easy to understand these conditions when we consider Figure 4. 7. On the horizontal axis we denote wealth and on the vertical axis the utility. The upward sloping curve is the utility function of the car driver. Remember that his utility function is the same whether an accident happens or not.

Figure 4. 7: Utility of the car driver when cyclist takes less than due care



Equation (20) simply requires that the wealth when taking less than due care and paying for the losses lies left from the wealth when he takes due care. If this is not the case, the expected utility when taking less than due care is always higher than when taking due care and the car driver will not take due care. The condition (21) makes sure that we are on the bold line. In all cases on the bold line, the utility of taking due care is larger than the expected utility of taking less care. Hence if we want to be sure that the car driver takes due care, it must be the case that the probability of an accident when both take less than due care is large enough, this is larger than p_1.

(2) Car driver – cyclist takes due care

If the cyclist takes due care, the car driver also takes due care if this gives a higher utility.

$$\begin{aligned}&\left(1-p^{**}\right)U_i\left(w_0 - ac_i x_i^*, ac_i, 0\right) + p^{**}U_i\left(w_0 - ac_i x_i^*, ac_i, 1\right)\\ &\geq \left(1-p^{-*}\right)U_i\left(w_0 - ac_i x_i^-, ac_i, 0\right) + p^{-*}U_i\left(w_0 - ac_i x_i^- - pl_i - pl_j - npl_j, ac_i, 1\right)\end{aligned} \tag{22}$$

By Jensens inequality we know that this is the case if and only if

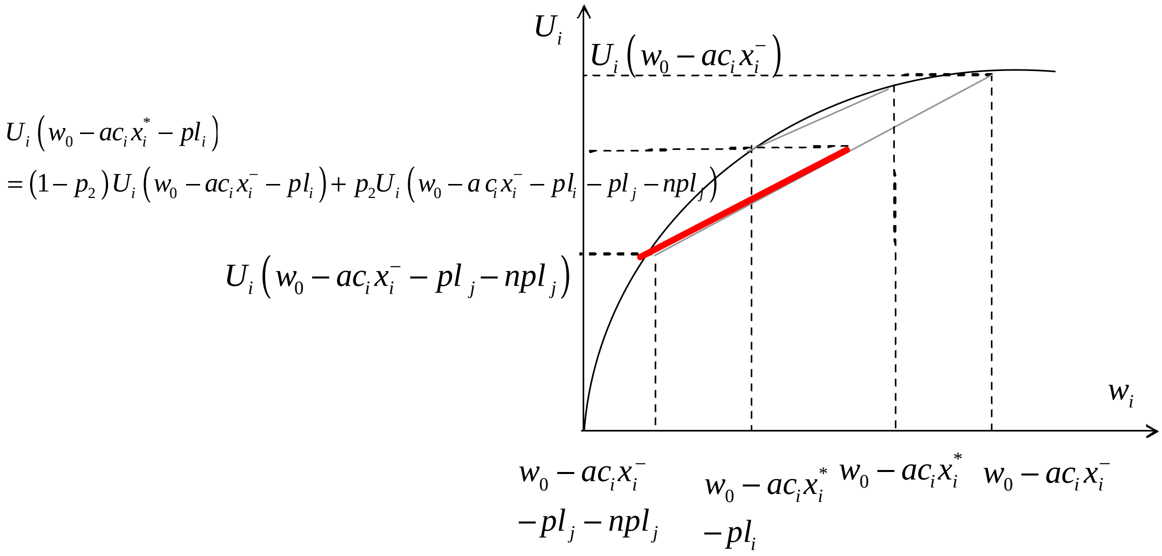
$$\begin{aligned}&w_0 - ac_i x_i^- - pl_i - pl_j - npl_j \leq w_0 - ac_i x_i^* - pl_i\\ &\Rightarrow ac_i x_i^* \leq ac_i x_i^- + pl_j + npl_j\end{aligned} \tag{23}$$

Note that this is the same condition as in (20). In order to make sure that the utility when taking due care is always larger than when taking less care we also need that the probability of an accident when the car driver takes less than due care and the cyclist takes due care is large enough. This is, we want

$$p^{-*} > p_2$$
$$\text{with } p_2 : U\left(w_0 - ac_i x_i^* - pl_i, ac_i, 0\right) = \left(1 - p_2\right) U\left(w_0 - ac_i x_i^-, ac_i, 0\right) + p_2 U\left(w_0 - ac_i x_i^- - pl_j - npl_j, ac_i, 1\right) \tag{24}$$

We see this in Figure 4. 8, which has the same structure as Figure 7.

Figure 4. 8: Utility of the car driver when the cyclist takes due care



If we want that the utility of taking due care is always higher than taking less care, we need to make sure that we are on the bold part of the line. There the expected utility of taking less than due care is always lower than taking due care.

(3) Cyclist- car driver less than due care

If we want to be sure that the cyclist takes due care when the car driver takes less care, we first require that

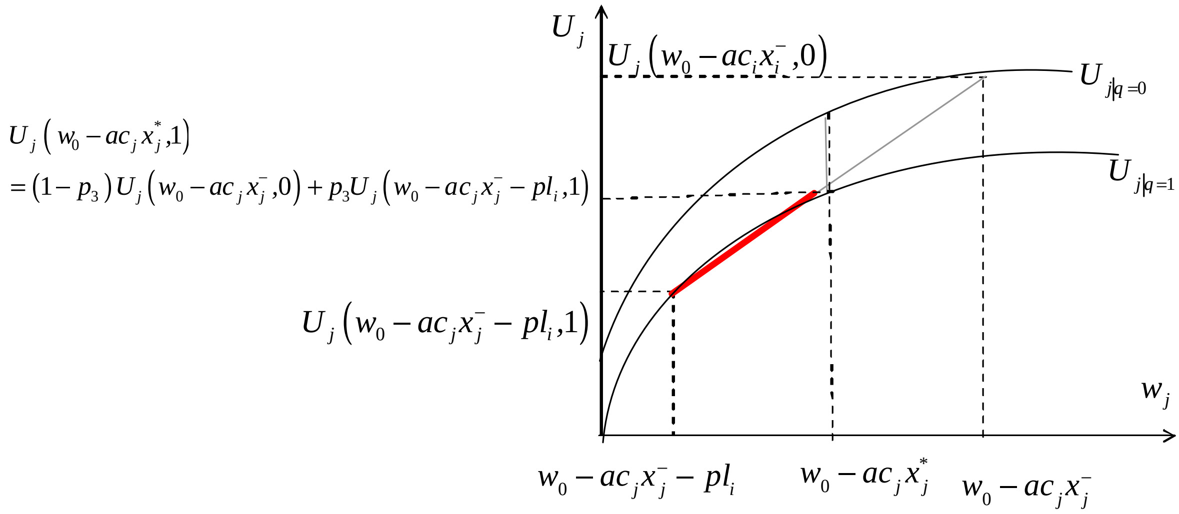
$$\begin{aligned} & w_0 - ac_j x_j^- - pl_i \le w_0 - ac_j x_j^* \\ & \Rightarrow ac_j x_j^* \le ac_j x_j^- + pl_i \end{aligned} \tag{25}$$

We also need that

$$\begin{aligned} & p^{--} > p_3 \\ & \text{with } p_3 : U\left(w_0 - ac_j x_j^*, ac_j, 1\right) = \left(1 - p_3\right) U\left(w_0 - ac_j x_j^-, ac_j, 0\right) + p_3 U\left(w_0 - ac_j x_j^- - pl_i, ac_j, 1\right) \end{aligned} \tag{26}$$

Hence we need that p^{--} satisfies condition (26) and (21), where condition (26) imposes the strict condition. Hence equation (21) is superfluous. This is shown in Figure 4. 9 where on the horizontal axis we denote the wealth and on the vertical the utility. The highest upward sloping curve represents the utility when the cyclist is not involved in an accident, the other lower curve shows the utility when he is hit by a car.

Figure 4. 9: Utility of cyclist when car driver takes less than due care



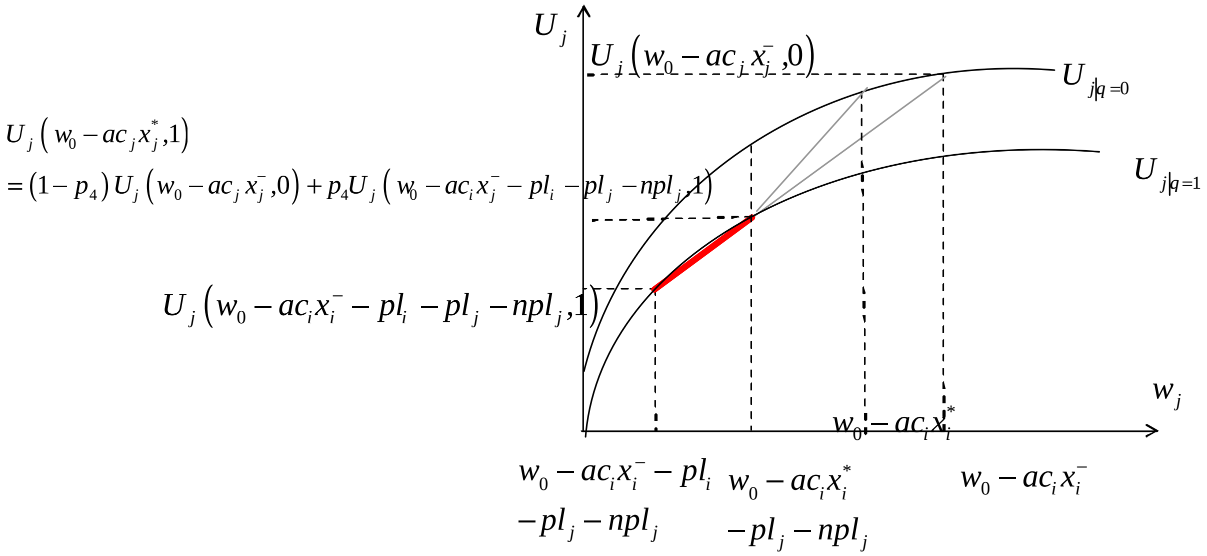
(4) Cyclist – car driver takes due care

We again need condition (25) and the condition that the probability of an accident when the car driver takes due care and the cyclist less than due care is high enough if we want the cyclist to take due care.

$$\begin{aligned} & p^{-*} > p_4 \\ & \text{with } p_4 : U\left(w_0 - ac_j x_j^*, ac_j, 1\right) = (1-p_4)U\left(w_0 - ac_j x_j^-, ac_j, 0\right) + p_4 U\left(w_0 - ac_j x_j^- - pl_i - pl_j - npl_j, ac_j, 1\right) \end{aligned} \tag{27}$$

We show this graphically on Figure 4. 10, which has the same structure as Figure 4. 9.

Figure 4. 10: Utility cyclist when car driver takes due care



5

Traffic Safety: Speed Limits, Strict Liability and a Km tax

Eef Delhaye

1. INTRODUCTION

Road accidents are a serious public health problem and impose a serious economic burden. They are estimated to represent up to 4 per cent of GDP in some countries (OECD, 2002). Therefore it is not surprising that there is intensive activity in many European countries to combat road accidents. The government can use different instruments to improve traffic safety such as regulation (speed limits[75], vehicle standards, etc.) and its enforcement, liability rules (strict liability, negligence), physical measures (roundabouts, speed humps, etc.), economic instruments (road pricing, insurance, etc.), education and sensitisation.

Here we focus on the behaviour of people because 85 per cent of all accidents are mainly due to road users' error (Lonero et al, 1995); more particularly, we focus on their choice of speed and on the number of kilometres they drive. We consider three specific instruments: a speed limit, strict liability[76] and a kilometre tax. Car drivers may be induced to drive at a reasonable speed by letting them bear the accident cost

---

[75] Note that speed limits only influence traffic safety if there is no congestion.

[76] Strict liability means that if A damages B, then A is liable for that damage.

(liability) and/or by setting speed limits and enforcing them (regulation). The activity level, this is the number of kilometres one drives can be influenced by strict liability and by the use of a tax. Indirectly, the activity is influenced by regulation because it is a function of speed.

We use a theoretical model of traffic accidents based on Shavell (1984a) to analyse the choice of speed and activity of people under the different instruments. His model provides a framework which considers regulation and liability as means to control accident risks. We apply this model to traffic safety and extend it by incorporating the activity level, a kilometre tax and imperfect compliance with the speed limits. Note that we do not take into account the existence of congestion, or the effect that accidents have on congestion or the effect that congestion has on the expected accident cost. Verhoef et al (2004) integrate speed choice, safety and congestion. They analyse the influence of two instruments, a tax and a speed limit, on the flow, the speed and the density. However, in contrast to our model, their focus is more towards congestion and they explicitly take into account the presence of other drivers. They develop a behavioural model of traffic congestion and compare their results with the conventional economic models, which assume that the relation between traffic flow and speed is technical. They find that the congestion tax suggested by the conventional model are typically not optimal when you take other externalities, such as accidents, into account; that a minimum speed limit should be introduced; that speed limits in combination with a tax outperform speed limits used alone, which on its turn outperforms the use of a tax alone.

The structure of the paper is as follows. We first explain the assumptions we use to build our model. Secondly, we consider each instrument, strict liability, regulation and a kilometre tax as an instrument on its own. Next, we consider the behaviour of people under combinations of instruments. Note that in the base model we assume that people comply with regulation. This is obvious a strong simplification, which we relax in section five. Next, we illustrate the model with a numerical example. Finally, we conclude.

2. THE MODEL

We consider unilateral accidents. In this kind of accidents only one party, the injurer, can prevent the accident and the other party, the victim, bears all the losses. We assume that the losses can be expressed purely in pecuniary terms. Furthermore, we assume that both parties are risk neutral. Hence there is no need for insurance.

As an example throughout the text, we think of an accident between a bicycle and a car. We assume that only the car driver can take care by adjusting his speed and that if an accident happens only the cyclist experiences the losses[77].

For the individual car driver the cost of driving, $C(s,t)$ is a continuous function of speed, s, and the value of time, t. $C(s,t)$ comprises the time cost of the trip (with t the value of time), the resource costs and the own accident cost[78]. We assume that the cost of driving for a given value of time is decreasing and convex in the level of speed. The cost of driving at a given level of speed is increasing and linear in the value of time, $C_t > 0, C_{tt} = 0$. We also assume that if speed rises, the private cost decreases faster if the value of time is larger, $C_{st} < 0$. $C(s,t)$ reaches a minimum for a given value of t at speed $s^t_{private}$. We assume that people differ in their values of time. Hence, their transport cost, given a certain level of speed, will differ. People know their own value of time, but the government only knows the distribution of t[79]. $f(t)$ represents the probability density of t on [a,b], with $f(t)>0$, $0 \leq a < b$.

One of the main assumptions is that the accident costs are only determined by the level of speed and activity of the driver. We denote speed by s, $s \geq 0$. By driving more slowly, the car driver can lower the probability of an accident, $p(s)$ with $0 \leq p(s) \leq 1$, $p(0)=0$, $p'(s) > 0, p''(s) > 0$. We assume that the driver has perfect information on this

---

[77] In reality, the cyclist also influences the probability of an accident.

[78] Given that we assume unilateral accidents, the own accident costs are zero in our model. See for example Elvik (1994) and Peirson et al (1998) for a discussion of which costs are external and which are internal to the driver.

[79] The value of time is a function of the trip purpose, the income, etc. In the remainder of the text we assume that it only depends on the trip purpose. This trip purpose can change from trip to trip. It is difficult for the government to know the trip purposes of all people; hence it is plausible to assume that the government does not know the individual value of time.

probability function. Furthermore, we assume that the harm, h is the same for all accidents and independent of the level of speed[80]. The harm is known to the regulator.

Drivers also influence the accident cost by their activity level. In the literature one denotes as activity level everything that influences the social cost of an accident, but that is not included in a standard of due care set by the courts. Think for example of the number of times one looks into the rear mirror, the number of kilometres one drives, etc. In this setting we restrict the interpretation of the activity level to the number of kilometres one drives[81], which we denote by *ac*. We assume that the driver gets a certain utility of his activity level and that this utility is increasing in a decreasing way in the level of activity, $U'(ac)>0$, $U''(ac)<0$. We also assume that the private costs of driving and expected accident cost rise proportionally with the number of kilometres.

We can now calculate the private and the socially optimal levels of speed and activity.

2.1. Private and social optimum.

If neither the level of speed, nor the activity level is controlled for by the government, the driver will maximise his utility subject to his budget constraint. In his budget constraint he takes into account the cost of purchasing other goods[82] x, his private costs of driving $C(s,t)$ and his income y. Each driver will

$$\begin{aligned} &\max_{ac,s} U(ac) \\ &s.t.\, x + ac \cdot C(s,t) = y \end{aligned} \tag{1}$$

We form the Lagrangian[83], with $l > 0$, the marginal utility of income.

$$\max_{ac,s} U(ac) - l\left[ac \cdot C(s,t) + x - y\right] \tag{2}$$

---

[80] We can make the harm dependent on speed and not the probability or make both dependent. This will not change the results qualitatively as long as we assume that both the probability and the harm are increasing in the level of speed. Note that we can write the expected accident costs as $p(s)\cdot h = H(s) = p\cdot h(s) = p(s)\cdot h(s)$. Note that in Verhoef et al (2004) the expected accident costs depend on the own speed, the speed of the other drivers, the variance and the density of vehicles on the road and that both the probability and the harm depends on the speed.

[81] To control the number of kilometres, we can use a kilometre tax. Note that the number of times one looks into the mirror can not be influenced by a tax.

[82] We normalise the price of the other goods to one.

[83] In the remainder of the text we immediately write down the lagrangian.

This gives the private optimal level of speed, $s^t_{private}$ and activity, $ac^t_{private}$. The first order condition with respect to *x* gives

$$ac \cdot C_s(s,t) = 0 \Rightarrow C_s(s,t) = 0 \tag{3}$$

The private optimal speed, $s^t_{private}$ equals the minimum of the private cost function[84]. Note that it does not depend on the activity level. Given this speed, the private optimal activity, $ac^t_{private}$ is determined by the first order condition with respect to *ac*:

$$\frac{U'(ac)}{l} = C\left(s^t_{private}, t\right) \tag{4}$$

He will increase his activity level as long as the marginal utility of doing this is larger than the private cost of it.

We maximise social welfare with respect to the level of speed and activity for each value of time and for a given level of harm. The social welfare equals the utility one obtains from the activity, taking into account the private and external cost of driving. Comparing (5) and (1) it is clear that in this setting the external cost equals the expected accident costs, $ac \cdot p(s)\bar{h}$.

$$\max_{ac,s} U(ac) - l\left[ac\left(C(s,t) + p(s)\bar{h}\right) + x - y\right] \tag{5}$$

Deriving (5) with respect to the level of speed leads to the first order condition

$$C_s(s,t) = p'(s)\bar{h} \tag{6}$$

This gives the first-best level of speed $s^*(t,h)$. The condition states that, for every *t* and $\bar{h}$, the marginal cost of lowering one's speed should equal the marginal benefit. The marginal benefit equals the marginal (reduction in) accident risk times the harm. We can prove[85] that for a given harm, $\bar{h}$ the socially optimal speed level is an increasing

---

[84] This coincides with the findings of Rothengatter (1991). He found that speed is determined by four motivational factors; these are the pleasure of driving, the travel risk, the travel time and the driving costs. Our model explicitly takes into account the last three factors and can easily take into account, for example by including an additional component in the cost function, the first factor. This would increase the number of driver types and hence influence the performance of uniform measures but would not change the analysis.

[85] The proofs can be found in Appendix 5A.

function of the value of time, $s_t^*\left(t,\bar{h}\right) \geq 0$. We can also prove that for a given value of time $\bar{t}$, the socially optimal level of speed is decreasing in the level of harm, $s_h^*\left(\bar{t},h\right) < 0$.

Given the socially optimal level of speed, the socially optimal level of activity for each t and given $\bar{h}$ is given by

$$\frac{U'\left(ac\right)}{l} = C\left(s^*,t\right) + p\left(s^*\right)\bar{h} \tag{7}$$

In words, the marginal benefit of raising the number of kilometres should cover the private cost of driving and the expected cost of an accident, when driving at the socially optimal speed. We can prove that the socially optimal activity level decreases in the value of time and in the level of harm.

Again, as with the level of speed, when we compare (7) and (4), we see that the private optimum does not equal the social optimum. In the private optimum the driver does not take into account the full costs of driving an extra kilometre.

We conclude that if the government does not influence the behaviour of the driver, nor the level of speed, nor the activity level will be optimal. The driver will drive too fast and too many kilometres. The government can influence the behaviour of the driver by the use of regulation, strict liability and a kilometre tax. We first discuss the instruments used separately. In section three, we consider some combinations.

2.2. Strict Liability

Strict liability means that if an accident happens, the car driver is always liable, whatever his level of speed at the time of the accident. This reflects the Belgian legislation on accidents between car drivers and vulnerable road users.

In a perfect world with perfect information, the driver then fully internalises the accident costs and strict liability leads to the optimal solution. The fact that the victim does not carry any losses does not play a role since he has no influence on the probability of an accident. In the real world however, strict liability faces two main problems. The first problem is referred to in the literature as ‘judgement proof’. This means that in reality some people cannot pay for the damages they cause[86]. Given an estimate for the value of a life of 1.670.000 euro (UNITE, 2001), this is not unrealistic. The same effect on the behaviour of people results if they do not have to pay the full damages. This is not an unrealistic assumption as courts often make wrong estimates. Judgment proof makes that drivers do not take into account the full accident cost. A second problem is the fact that the probability of being held liable is not always equal to one. Think for example of hit and run drivers. Again, this means that people do not take into account the full accident cost. If drivers underestimate the probability of an accident or overestimate their capabilities, this has the same effect.

Denote the probability of conviction by q, $0 \le q < 1$. In this paper we assume that q is exogenously given, this is, q is not an instrument of the government. We assume that the income, y and the probability of conviction q are the same for all drivers. The injurer pays h if $h \le y$, otherwise he pays y.

For a given level of harm, $\bar{h}$ and for each value of time, t, the car driver maximises his utility taking into account the costs of driving and the expected liability costs. He will

$$\max_{ac,s} U(ac) - l\left[\left(ac\left(C(s,t) + q \cdot p(s)\, min\left\{\bar{h}, y\right\}\right)\right) + x - y\right] \qquad (8)$$

This leads to $s_L\left(t,\bar{h}\right)$. When we compare (8) with (5) we find that under strict liability, given the harm, the speed at which people drive as a function of their value of time, equals the socially optimal speed with the harm equal to $q\min\left\{\bar{h}, y\right\}$. This level of speed is higher than the actual socially optimal speed given the harm $\bar{h}$[87]:

$$s_L\left(t,\bar{h}\right) = s^*\left(t, q\,min\left\{\bar{h}, y\right\}\right) \ge s^*\left(t,\bar{h}\right) \qquad (9)$$

---

[86] Remember that we do not take into account the existence of insurance.

[87] Proof: Since (8) is identical in form to (5), it is clear that for all t, $s_L\left(t,\bar{h}\right)$ is determined by the first equality in (9). To prove the inequality, note that we proved that $s^*\left(\bar{t},h\right)$ is decreasing in h and that $h \ge q\,min\{h,y\}$.

We present this case graphically in Figure 5. 1. On the horizontal axis we find the level of speed, on the vertical axis the costs expressed in euro. The upward sloping curves represent the derivative of the private cost functions for each value of time and the downward sloping curve represents minus the derivative of the expected accident cost. Their intersection determines the socially optimal level of speed. Note that for $t_1 < t_2$, $s_1^* < s_2^*$. The private optimal level of speed is determined by the intersection of the derivative of the private cost function with the horizontal axis. The levels of speed under strict liability are given by the intersections of the derivative of the private cost functions and the derivative of the expected liability cost, $-qp'(s)\min\{h,y\}$.

Figure 5. 1: Speed level under strict liability (*q*<1)

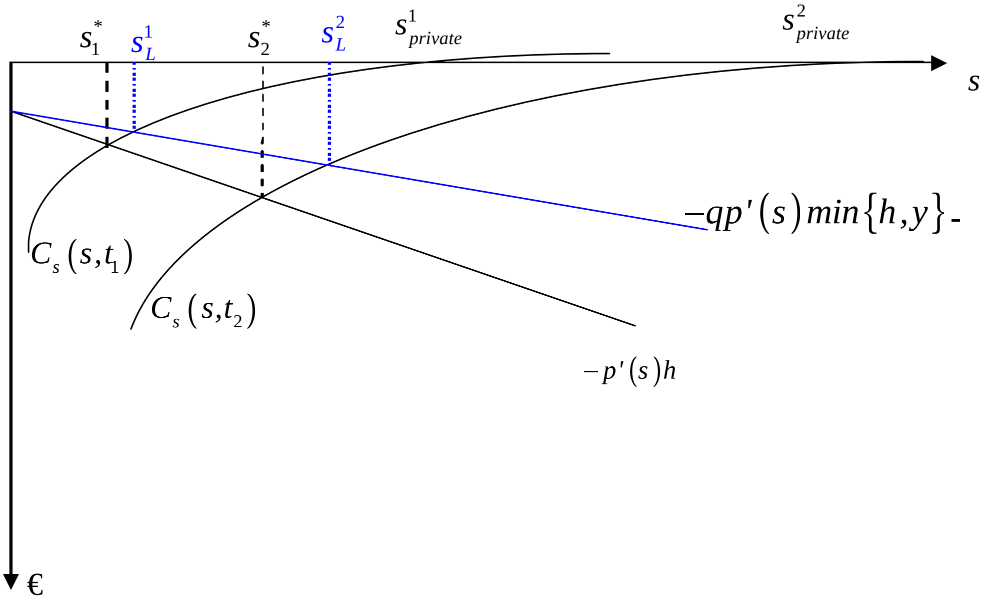


Figure 5. 1 shows that strict liability, used as the only regulatory instrument, causes people to drive too fast with respect to the optimal solution. The reason is that, because of the judgement proof problem and the positive chance of the responsible driver not being sued, they do not take into account the full expected accident cost. Remark that in setting the fine, courts could take into account that q<1 by correcting the fine with a factor *1/q*. This would raise the expected liability cost for the driver, but it also increases the problem of judgement proof.

Given this level of speed, the activity level under strict liability, $ac_L(t,\bar{h})$ will be given by

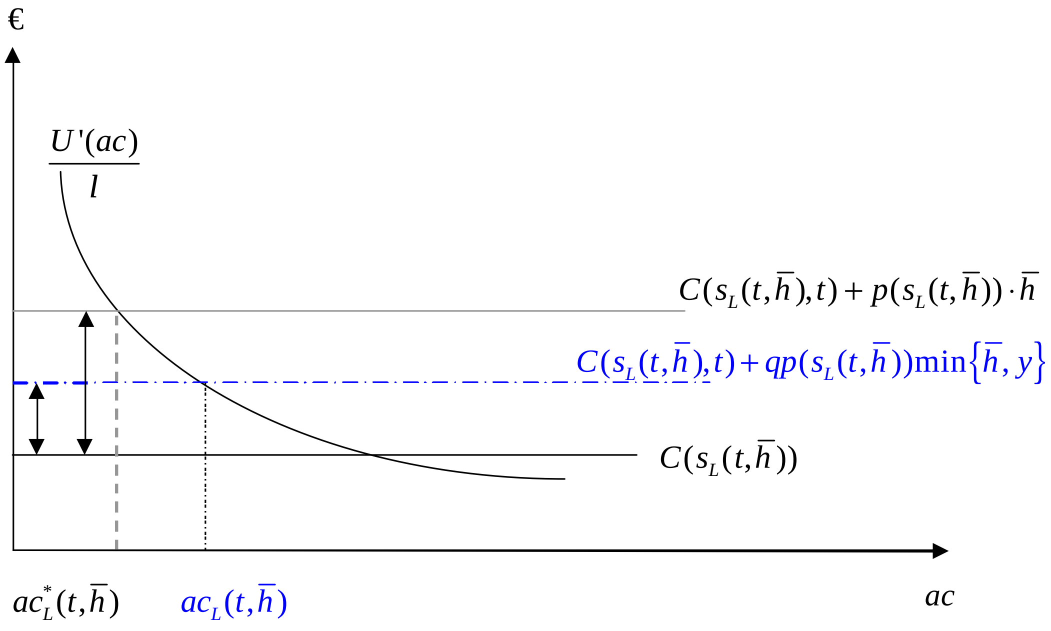
$$\frac{U'(ac)}{l} = C\left(s_L\left(t,\bar{h}\right),t\right) + q \cdot p\left(s_L\left(t,\bar{h}\right)\right) min\left\{\bar{h},y\right\} \tag{10}$$

The optimal activity level given this level of speed is determined by maximising the utility taking into account the private costs and the expected accident costs.

$$\begin{aligned} &\max_{ac,s} U(ac) - l\left[ac\left(C\left(s_L\left(t,\bar{h}\right),t\right) + p\left(s_L\left(t,\bar{h}\right)\right)\bar{h}\right) + x - y\right] \\ &\Rightarrow \frac{U'(ac)}{l} = C\left(s_L\left(t,\bar{h}\right),t\right) + p\left(s_L\left(t,\bar{h}\right)\right)\bar{h} \end{aligned} \tag{11}$$

Compare (10) with (11). The private costs are equal but the expected accident cost is larger than the expected liability cost. This means that the right-hand side of (11) is larger than the right hand side of (10). Hence the marginal utility of activity should cover a higher cost per unit of activity in the social optimum than under strict liability. Hence he will drive too much under strict liability. This is also shown on Figure 5. 2. On the horizontal axis we denote the activity level, on the vertical axis the costs expressed in euro. The downward sloping curve represents the marginal utility of activity, the horizontal curves the marginal costs of being involved in the activity.

Figure 5. 2: Activity level under strict liability



2.3. *Regulation*

One of the best known types of regulation in traffic are speed limits. Since speed is the decision variable in our model, we concentrate on this type of regulation. Because of the differences in time values it would be optimal to set a different standard for each value of time. The regulator lacks the information to do this and sets a uniform standard. This is also what we observe in the real world. Following Shavell (1984a), we implicitly assume that all parties comply with regulation. Given the number of speed violations, this is not a realistic assumption. It would therefore be interesting to see what happens to the model if we allow for non-compliance. This will be done in section five as an extension, in which we also consider the optimal setting of the fines and the probability of detection.

Denote $\bar{s}$ as the regulatory standard. The regulator wants to maximise social welfare:

$$\begin{aligned} &\max_{ac,s} U(ac) - l\left[ac\left(\int_a^b C(s,t)\,f(t)\,dt + p(s)\bar{h}\right) + x - y\right] \\ &= \max_{ac,s} U(ac) - l\left[ac\left(E\left[C(s)\right] + p(s)\bar{h}\right) + x - y\right] \end{aligned} \tag{12}$$

This gives the first order condition with respect to s

$$\begin{aligned} &E\left[C'(s)\right] = -p'(s)\bar{h} \\ &\Rightarrow C'(s, E[t]) = -p'(s)\bar{h} \qquad \text{(C linear in t)} \end{aligned} \tag{13}$$

This gives $\bar{s}$, the unique optimal regulatory standard[88]. Note that $\bar{s}$ equals the level of speed that would be first best for the party with the average value of time[89]:

$$\bar{s} = s^*\left(E[t], \bar{h}\right) \tag{14}$$

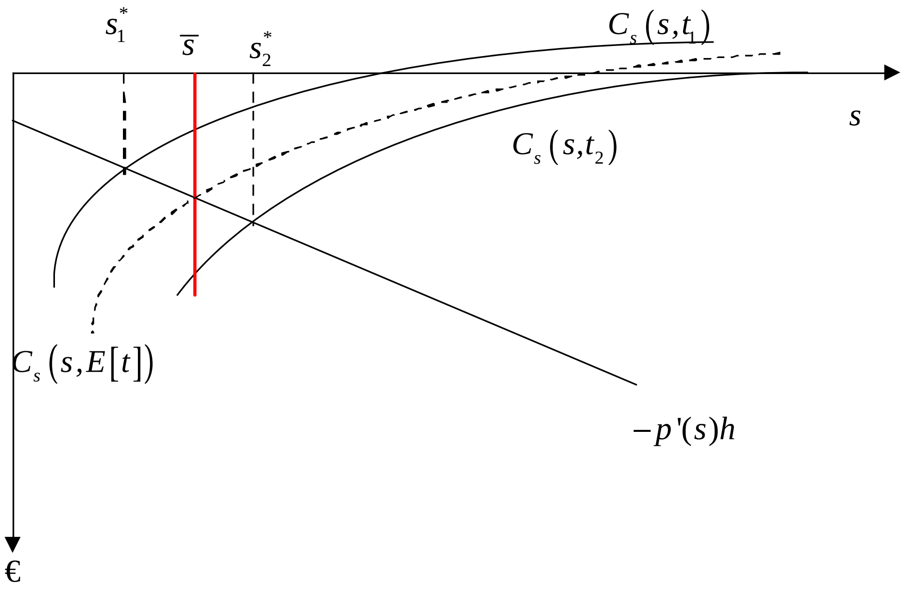
---

[88] This is a first best solution. In the second best solution we should take into account that the speed limit does not control the activity level directly and add an additional constraint (with Lagrange multiplier m) stating that the marginal benefit of driving should equal the marginal cost. However, in this case, the first best solution equals the second best if one of the constraints is binding $\left(m, l > 0 \vee m = 0, l > 0 \vee m > 0, l = 0\right)$.

[89] Proof: to prove that $\bar{s} = s^*\left(E[t], \bar{h}\right)$ compare FOC (6) and FOC (13). $\bar{s}$ is unique since $C_s < 0, C_{ss} > 0$ and $p_s > 0, p_{ss} > 0$. ¦

This is illustrated in Figure 5. 3. The broken line in Figure 5. 3 represents the derivative of the private cost function for the average value of time. The standard is set at the intersection of the derivative of the expected accident cost function and the private cost function for $t = E[t]$. For some values of time, such as t_2, the regulation will be too strict, while for others, such as t_1, the regulation is too loose.

Figure 5. 3 : Speed level under regulation



In general, the number of kilometres one drives will not be regulated. Given that we assume perfect compliance, the driver will maximise his utility taking into account his private cost of driving at the speed limit.

$$\max_{ac} U(ac) - l\left(ac \cdot C(\overline{s},t) + x - y\right) \tag{15}$$

The number of kilometres under regulation, $ac_{\overline{s}}(t,\overline{h})$, is then determined by

$$\frac{U'(ac)}{l} = C(\overline{s},t) \tag{16}$$

The optimal number of kilometres, $ac_{\overline{s}}^*(t,\overline{h})$ given the speed limit $\overline{s}$ is determined by

$$\frac{U'(ac)}{l} = C(\overline{s},t) + p(\overline{s})\overline{h} \tag{17}$$

Comparing (17) with (16), it is clear that the driver does not take into account the expected accident cost in determining the number of kilometres. Hence, he will drive too much.

2.4. Kilometre tax used alone

A possible instrument to influence the number of kilometres one drives is a tax on the level of activity, tax_{ac}.

The driver will maximise his utility taking into account his private costs and the tax.

$$\max_{ac,s} U(ac) - l\left(ac \cdot C(s,t) + ac \cdot tax_{ac}^{t} + x - y\right) \tag{18}$$

The level of speed under a kilometre tax, s_{tax}^{t} is determined by

$$C_s(s,t) = 0 \tag{19}$$

This is, under the use of only a kilometre tax, the government will not affect the level of speed and speed will equal the private optimal speed. The government takes this into account in setting the tax.

The number of kilometres under a kilometre tax, ac_{tax}^{t} is determined by

$$\frac{U'(ac)}{l} = C\left(s_{private}^{t}, t\right) + tax_{ac}^{t} \tag{20}$$

Given the level of speed, the government would like the drivers to determine their level of speed based on

$$\frac{U'(ac)}{l} = C\left(s_{private}^{t}, t\right) + p\left(s_{private}^{t}\right)\bar{h} \tag{21}$$

Comparing (20) and (21), it is clear that in the optimum the tax equals the external cost, $tax_{ac}^{*} = p\left(s_{private}^{t}\right)\bar{h}$. However, as with regulation, the government faces the problem that it has to set a uniform tax for all drivers, while the socially optimal activity level depends on the value of time. Hence he will set the tax equal to the expected value of the external costs, hence

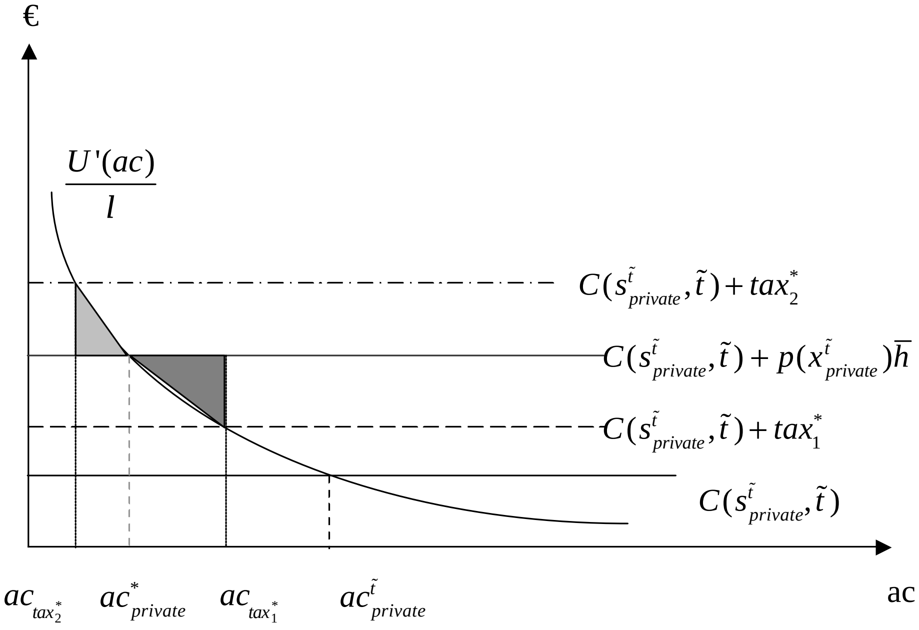
$$tax_{ac}^{*} = E\left[p\left(s_{private}^{t}\right)\bar{h}\right] \tag{22}$$

The activity level for each driver is then given by

$$\begin{aligned}\frac{U'(ac)}{l} &= C\left(s^{t}_{private},t\right)+tax^{*}_{ac} \\ &= C\left(s^{t}_{private},t\right)+E\left[p\left(s^{t}_{private}\right)\overline{h}\right]\end{aligned} \tag{23}$$

We represent this graphically in Figure 5. 4 for a driver with value of time $\tilde{t}$.

Figure 5. 4: Activity level under a kilometre tax



In general, the level of activity under a uniform tax will not equal $ac^{*}_{private}$, the optimal activity level given that the speed is $s^{\tilde{t}}_{private}$. Ex ante it is difficult to judge what the outcome will be. The private cost in (23) and (21) are equal. Whether the driver will drive too much or too little compared to the optimum depends on the magnitude of the tax relative to his expected accident cost. If for a person with a value of time $\tilde{t}$ $p\left(s^{\tilde{t}}_{private}\right)\overline{h} > E\left[p\left(s^{t}_{private}\right)\overline{h}\right]$, the tax will be too low, for example tax^{*}_{1}, and hence he will drive too much. The welfare loss of this tax is presented by the dark grey area. On the other hand, if $p\left(s^{\tilde{t}}_{private}\right)\overline{h} < E\left[p\left(s^{t}_{private}\right)\overline{h}\right]$ the tax is too high, for example tax^{*}_{2} and hence he will drive too little. The welfare loss of such a tax equals the light grey area in Figure 5. 4. Note that $p\left(s^{t}_{private}\right)\overline{h}$ rises in the value of time. Hence people with a low value of time will drive too little and people with a high value of time too much. Both types will certainly drive less than if there is no tax. Given that the tax takes into account that the people drive at their private optimal speed, the tax will be higher than if people would drive at the socially optimal level of speed. Hence the kilometre tax shall correct for some of accidents costs due to speeding.

3. JOINT USE

We now consider three combinations of the instruments, i.e. we analyse the joint use of regulation and strict liability, of regulation and a kilometre tax and of strict liability and a kilometre tax. In this article we mainly present the intuition. For the proofs and the full mathematical derivations we refer to Appendix 5B.

3.1. Regulation and strict liability

Under joint use of regulation and strict liability, drivers must satisfy the regulation and are liable for the damage done if an accident happens. In other words, they are also liable for the damage if they were not speeding at the time of the accident. Their level of speed will be given by $min\left\{\overline{s}, s_L\left(t,\overline{h}\right)\right\}$. This is, since we assume full compliance, people will never drive faster than the standard. However, they will drive more slowly than the standard if this minimises their expected cost.

The regulator takes this into account and maximise social welfare, this is he

$$\max_{s} U\left(ac\right) - l\left[ac\left(\int_a^b \left[C\left(min\left\{\overline{s}, s_L\left(t,\overline{h}\right)\right\}, t\right) + p\left(min\left\{\overline{s}, s_L\left(t,\overline{h}\right)\right\}\right)\overline{h}\right] f\left(t\right)dt + \right) + x - y\right] \tag{24}$$

Or, equivalently, he should choose between using strict liability alone, regulation alone or using regulation and strict liability jointly. The option which minimises the social costs should be chosen.

$$
\max_{s} U(ac) - l[x-y]
$$

$$
-l\left[ac\left[\min_{s}\left\{\begin{array}{l}
\underbrace{\min_{s_L(b,\bar{h})>\bar{s}>s_L(a,\bar{h})}\left(\int_{a}^{t(s)}\left[C\left(s_L(t,\bar{h}),t\right)+p\left(s_L(t,\bar{h})\right)\bar{h}\right]f(t)\,dt+\int_{t(s)}^{b}\left[C(s,t)+p(s)\bar{h}\right]f(t)\,dt\right)}_{\text{joint use of regulation and strict liability}} \\
\underbrace{\min_{\bar{s}\le s_L(a,\bar{h})}\int_{a}^{b}\left[C(s,t)+p(s)\bar{h}\right]f(t)\,dt;}_{\text{regulation alone}} \\
\underbrace{\min_{s_L(b,\bar{h})\le\bar{s}}\int_{a}^{b}\left[C\left(s_L(t,\bar{h}),t\right)+p\left(s_L(t,\bar{h})\right)\bar{h}\right]f(t)\,dt}_{\text{strict liability alone}}
\end{array}\right.\right]\right]
$$

(25)

We can prove that three situations can arise. Firstly, it could be optimal to set the standard so low, that no one drives slower than the speed limit. Speed is then only influenced by regulation, while strict liability dictates the activity level. Hence, people drive too much. Secondly, the standard can be set so high that no one drives at the speed limit; they all drive more slowly. In this case the government is actually using only strict liability as a measure. Regulation has nothing to add but cost. In the intermediate case, some people drive at the speed limit while other people drive more slowly. The people that drive more slowly are the people who drove too fast if regulation was used alone. Hence we are left with relatively more people who have to drive too slowly. Hence it is socially better to set the speed limit higher than if regulation is used alone. The activity level is, again, mainly influenced by the strict liability. Which case will occur depends on how badly strict liability is diluted and on the variability of the values of time.

3.2. Regulation and a kilometre tax

Under the joint use of regulation and a kilometre tax, regulation determines the level of speed but not the level of activity; the tax influences the activity but not the speed. The regulation makes that all people have to drive at the same speed. Hence some people drive too slow, others too fast.

Comparing (16) and (17) it is clear that the optimal tax under joint use equals the external cost given a speed limit $\bar{s}$,

$$tax_{jr}^{*} = p\left(\overline{s}\right)\overline{h} \tag{26}$$

Therefore the driver will then

$$\begin{aligned} &\frac{U'\left(ac\right)}{l} = C\left(\overline{s},t\right) + tax_{jr}^{*} \\ &\Rightarrow \frac{U'\left(ac\right)}{l} = C\left(s,t\right) + p\left(\overline{s}\right)\overline{h} \end{aligned} \tag{27}$$

Hence, the driver takes into account the full accident cost of driving at a speed limit $\overline{s}$. This means that the joint use of regulation and a kilometre tax leads to an activity level which is optimal given that speed is regulated.

3.3. Strict liability and a kilometre tax

Under the joint use of strict liability and a km tax people are strictly liable if an accident happens and they pay a tax on their activity level.

The kilometre tax does not influence the speed level. The level of speed will only be influenced by strict liability. Hence the driver maximises his utility, taking into account his private costs, his expected liability costs and the tax.

$$\max_{ac,s} U\left(ac\right) - l\left[ac\left(C\left(s,t\right) + qp\left(s\right)min\left\{\overline{h},y\right\} + tax_{jl}^{*}\right) + x - y\right] \tag{28}$$

The first order conditions with respect to the level of speed are

$$\begin{aligned} &-ac\left(C_{s}\left(s,t\right) + qp'\left(s\right)min\left\{\overline{h},y\right\}\right) = 0 \\ &\Leftrightarrow C_{s}\left(s,t\right) + qp'\left(s\right)min\left\{\overline{h},y\right\} = 0 \end{aligned} \tag{29}$$

Hence the speed will be as in the case where strict liability was used alone and people drive too fast.

For the driver, the first order condition with respect to the activity level then equals

$$\frac{U'\left(ac\right)}{l} = C\left(s_{L}\left(t,\overline{h}\right),t\right) + qp\left(s_{L}\left(t,\overline{h}\right)\right)min\left\{\overline{h},y\right\} + tax_{jl}^{*} \tag{30}$$

Both instruments influence the activity level. Strict liability makes that the driver takes into account part of the accident costs, but because of the two problems we discussed earlier not the full costs. Therefore his activity is already lower than the private optimum. The tax is then optimally set to the remainder of the accident cost of the driver. However the tax is uniform and hence, again, for some the tax is set too high, for others too low.

4. CHOICE OF INSTRUMENTS

Which instrument or which combination should the government choose? The answer depends on the probability of conviction, the level of assets relative to the harm and on the variability of the values of time.

To make things clear, we summarize the results of the analysis in Table 5. 1.

Table 5. 1: Overview measures

Measure		Speed	Number of kilometres
Strict liability	$q=1, \bar{h} \leq y$	Optimal	Optimal
	$q<1$ and/or $\bar{h}>y$	Too high	Too high
Regulation	uniform	$t<E[t]$: too high $t>E[t]$: too low	No influence, hence too high
Kilometre tax	uniform	Too high	Too high/too low
Strict liability ($q<1$ and/or $\bar{h}>y$) + regulation		$t<t(\bar{s})$: too high $t \geq t(\bar{s})$:too high/too low	Too high
Kilometre tax + strict liability		Too high	Too high/too low
Kilometre tax + regulation		$t<E[t]$: too high $t>E[t]$: too low	Optimal

In our setting, if there is no judgement proof problem and if the probability of being held liable equals one, strict liability leads to the optimal solution. If strict liability does not work perfectly, both the level of speed and the activity level are too high.

Under regulation, some drive too fast, others too slow. The activity level is not directly influenced under regulation. People choose their activity level, taking into account the private cost of driving at the speed limit, but not taking into account the expected accident cost. Therefore people drive too much.

A kilometre tax used alone does not influence the level of speed and hence people drive too fast. Since the kilometre tax is uniform, some people will drive too much and others too little.

Three situations can occur under the joint use of regulation and strict liability. In the first case, the speed limit is such that people with a high value of time stick to the speed limit, while people with a low value of time drive even slower due to the strict liability. Secondly, it could be optimal to set the standard so low that all drive at this limit. No one drives slower. Speed is then only influenced by regulation; hence some people will drive too slow, others too fast. Finally, the standard can be set so high that all drive more slowly than the speed limit. In this case the government is actually using only strict liability as a measure. In all three cases we find that some people drive too slowly, others too fast. The activity level is in the three cases mainly influenced by strict liability. Hence people drive too much.

Under the joint use of a kilometre tax and strict liability people are strictly liable if an accident happens and they pay a tax on their activity level. The kilometre tax does not influence the speed level. The level of speed will only be influenced by strict liability. Hence people drive too fast. Both instruments influence the activity level. Strict liability makes that the driver takes into account part of the accident cost. The tax is then set to the remainder of the accident cost. However, the tax is uniform and hence for some the tax is set too high, for others too low.

Joint use of a kilometre tax and regulation also does not lead to an optimal speed level but the activity level will be optimal. Therefore, if we only care about the activity level this combination should be preferred. However, we have to take into account that, in general, regulation does not lead to the socially optimal level of speed.

If there is only one value of time, it is of course optimal to use regulation and a kilometre tax jointly[90]. If the variability of the values of time is high and if strict liability works almost perfectly, strict liability will be preferred. In general, we should calculate

---

[90] However if strict liability works perfectly this also leads to the social optimum. Since we do not consider the costs of the measures, the government is then indifferent.

the welfare losses of the different measures and choose the measure with the lowest social cost.

5. IMPERFECT COMPLIANCE AND ENFORCEMENT

In the analysis up to now, we assumed that people comply with the regulation. If there is no enforcement, this will not be true. Even with enforcement, not all people comply. In this extension we go deeper into the theory of enforcement. We base ourselves on the analysis of Polinsky and Shavell (2000).

For this analysis we keep the level of activity fixed. We only focus on the level of speed. Moreover, we focus on the case in which only regulation is used. We still assume that accidents are unilateral, that only the victim has losses and that people are risk neutral. First, we introduce some notation; next, we consider the optimal setting of the fine and the level of detection. Using backward induction we first consider the behaviour of the individual. Given this behaviour, the government will set the fine, the probability of detection and the speed limit in order to maximise the social welfare. Finally, we analyse how imperfect compliance influences the analysis made above.

5.1. Notation

We denote the level of the fine as a function of the level of speed by

$$j\left(s\right) \text{ with } \begin{cases} j\left(\mathrm{s}\right)=0 \text{ for } s \le \overline{s} \\ j\left(\mathrm{s}\right)>0 \text{ for } s > \overline{s} \end{cases} \tag{31}$$

If one drives faster than the speed limit, the fine is positive, if one drives at the speed limit or slower, the fine is zero. Enforcement comes at a cost. There are two kinds of costs, fixed costs, fe, and variable costs, ve. The fixed costs do not depend on the number of speeders, the variable costs do. An example of fixed costs is the cost of radar control equipment; an example of variable costs is the administrative cost of collecting a fine. The probability of detection of a speeder, $p\left(fe\right)$ is a function of the fixed enforcement costs, with $p'\left(fe\right)>0, p''\left(fe\right)<0$. Note that this probability does not depend on the level of speed.

5.2. *Behaviour of the driver*

Without enforcement, the driver drives at his private optimal speed. With enforcement, an individual speeds if the cost of doing so, taking into account the expected fine, is lower than driving at the regulated speed. Since regulation is used alone, he will not take into account the accident cost. The driver will speed if

$$\begin{aligned} & C(\bar{s},t) > C(s,t) + p\,(fe)\,j\,(s) \\ \Leftrightarrow\ & C(\bar{s},t) - C(s,t) > p\,(fe)\,j\,(s) \end{aligned} \tag{32}$$

He will speed if the difference in private costs, which is the gain of speeding, is larger than the expected fine. There exists a driver with a value of time such that the above holds with equality, this is

$$\begin{aligned} & \exists\tilde{t} : C(\bar{s},\tilde{t}) - C(s,\tilde{t}) = p\,(fe)\,j\,(s) \\ & \text{with} \begin{cases} \forall t \le \tilde{t}\text{: comply with regulation} \\ \forall t > \tilde{t}\text{: speed} \end{cases} \\ & \text{and } \tilde{t} = t\big(j\,(s)\big),\ \text{with } t'\big(j\,(s)\big) > 0 \end{aligned} \tag{33}$$

5.3. *Government*

The government has now three decisions to make. It has to determine the level of detection via fe, the level of the fine, $j\,(s)$ and the speed limit. It will first set an optimal fine, minimising the social costs[91] and taking into account the behaviour of the driver, this is, it will

$$\min_{j\,(s)} \left[\underbrace{\int_{a}^{\tilde{t}(j)} \left[C(\bar{s},t) + p(\bar{s})\bar{h} \right] f\,(t)\,dt}_{comply} + \underbrace{\int_{\tilde{t}(j)}^{b} \left[C(s,t) + p(s)\bar{h} + ve \cdot p\,(fe) \right] f\,(t)\,dt + fe}_{speeding} \right]$$

(34)

We use Leibniz rule and obtain the following first order condition:

$$C\big(\bar{s},\tilde{t}\,(j\,)\big) - C\big(s,\tilde{t}\,(j\,)\big) = \big(p(s) - p(\bar{s})\big)\bar{h} + ve \cdot p\,(fe) \tag{35}$$

Substituting (33) in (35), we obtain

---

[91] For this analysis we keep the activity level fixed. Note that maximising utility/welfare then equals minimising private costs/social costs.

$$
\begin{aligned}
&p(fe)j(s) = \left(p(s) - p(\bar{s})\right)\bar{h} + ve \cdot p(fe) \\
&\Leftrightarrow j(s) = \frac{\left(p(s) - p(\bar{s})\right)\bar{h}}{p(fe)} + ve
\end{aligned}
\tag{36}
$$

We conclude that the optimal fine is a function of speed and equals the sum of the difference in expected accident costs due to speeding, corrected for the probability of detection and the variable enforcement costs. Logically, if the harm rises, or the probability of detection decreases or if the variable costs rise, the fine becomes larger. We assume that people can pay the fine.

For the driver with value of time $\tilde{t}$ we find that

$$
\begin{aligned}
&C(\bar{s},\tilde{t}) = C(s,\tilde{t}) + p(fe)j(s) \\
&\Rightarrow C(\bar{s},\tilde{t}) = C(s,\tilde{t}) + \left(p(s) - p(\bar{s})\right)\bar{h} + ve \cdot p(fe) \\
&\Rightarrow C(\bar{s},\tilde{t}) + p(\bar{s})\bar{h} = C(s,\tilde{t}) + p(s)\bar{h} + ve \cdot p(fe)
\end{aligned}
\tag{37}
$$

For people with $t > \tilde{t}$ we find that

$$
C(\bar{s},t) + p(\bar{s})\bar{h} = C(s,t) + p(s)\bar{h} + ve \cdot p(fe) \tag{38}
$$

Hence, the people that speed are people for whom the social cost of driving at the speed level is higher than the social cost of driving faster, corrected for the expected variable costs of enforcement. Hence, it is socially optimal that those people speed. Remember that in the base scenario, the speed limit was too strict for $t > E[t]$ and that we found that

$$
C(\bar{s},E[t]) + p(\bar{s})\bar{h} = C(s,E[t]) + p(s)\bar{h} \tag{39}
$$

Comparing (39) and (37) it is clear that $\tilde{t} > E[t]$. Hence the people that speed $\left(t > \tilde{t} > E[t]\right)$ are people that had to drive too slowly under regulation with perfect compliance.

Given the expression for the optimal fine, the government will set the level of detection, taking into account the costs. He minimises the social costs with respect to the fixed enforcement costs.

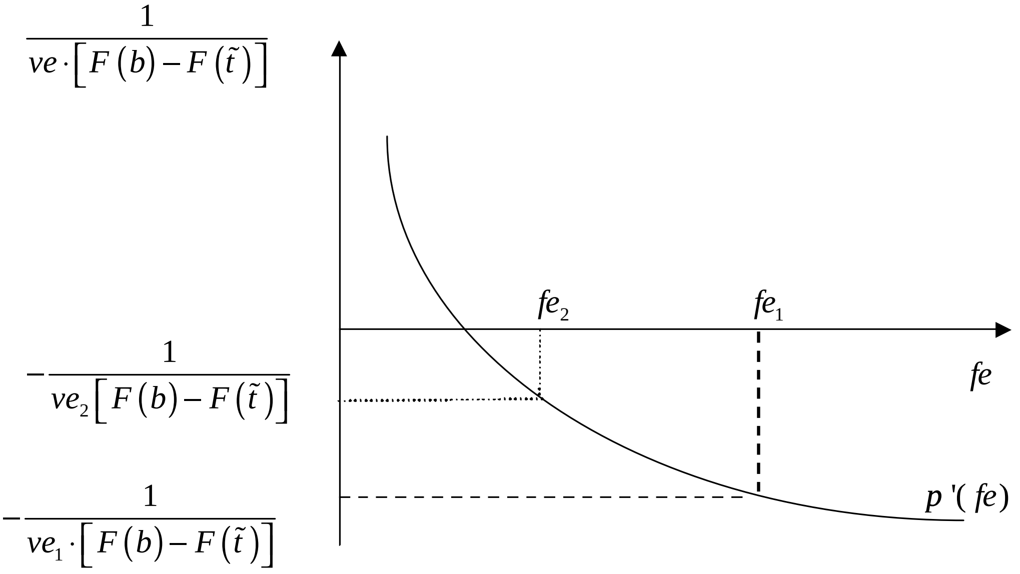
$$\min_{fe}\left[\int_a^{\tilde t}\left[C(\bar s,t)+p(\bar s)\bar h\right]f(t)dt+\int_{\tilde t}^{b}\left[C(s,t)+p(s)\bar h+ve\cdot p(fe)\right]f(t)dt+fe\right]$$

$$\Rightarrow ve\cdot p'(fe)\int_{\tilde t}^{b} f(t)dt=-1 \tag{40}$$

$$\Rightarrow p'(fe)=-\frac{1}{ve\left[F(b)-F(\tilde t)\right]}$$

(40) determines the level of fixed cost, *fe*, and hence $p(fe)$. The probability of detection depends on the variable costs, *ve*, the distribution of the values of time and the speed at which the probability of detection increases if the fixed costs increases. We illustrate this graphically in Figure 5. 5. On the horizontal axis we find the fixed costs, on the vertical axis the inverse of the variable costs, corrected for the distribution of the values of time.

Figure 5. 5: Optimal fixed enforcement costs



In Figure 5. 5 we see that if the variable enforcement costs increase, $(ve_2 > ve_1)$, the optimal fixed enforcement spending decreases, $(fe_2 < fe_1)$, and hence the probability of detection decreases. The expected fine however remains the same, since the fine will then increase. It makes sense that if the variable enforcement increases, the probability of detection decreases, since every time you detect someone you have to pay the variable enforcement costs. If $\tilde{t}$ goes to b, this is there are less people for which it is optimal to drive too fast, the right-hand side of (40) becomes more negative, and hence the fixed enforcement cost increase. If the probability in detection rises faster in *fe*, *fe**, quite logical, decreases.

5.4. Effect on previous analysis

How does the relaxation of perfect compliance influence the analysis? The government still has to determine the optimal speed level. Minimising the social cost with respect to the speed limit, *s*, leads to the following first order condition

$$\min_{\bar{\bar{s}}}\left[\int_a^{\tilde{t}}\left[C\left(\bar{\bar{s}},t\right)+p\left(\bar{\bar{s}}\right)\bar{h}\right]f\left(t\right)dt+\int_{\tilde{t}}^{b}\left[C\left(s,t\right)+p\left(s\right)\bar{h}+ve\cdot p\left(fe\right)\right]f\left(t\right)dt+fe\right]$$

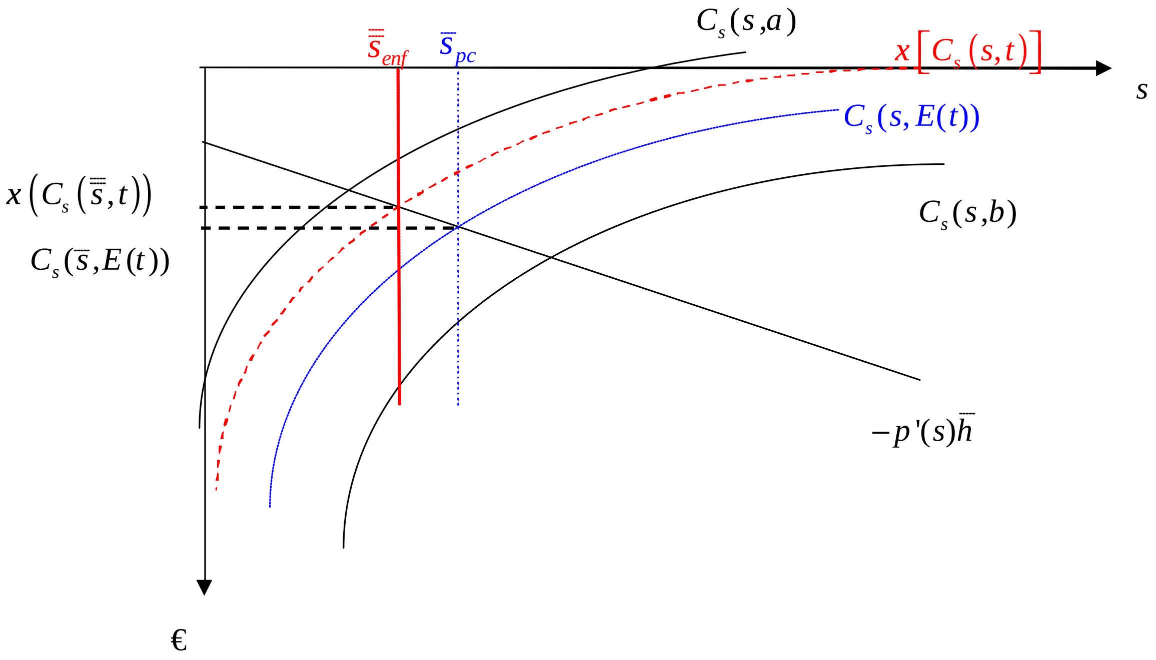
$$\Rightarrow\int_a^{\tilde{t}}C_s\left(\bar{\bar{s}},t\right)f\left(t\right)dt+p'\left(\bar{\bar{s}}\right)\bar{h}\int_a^{\tilde{t}}f\left(t\right)dt=0$$

$$\Rightarrow\int_a^{\tilde{t}}f\left(t\right)dt\left[p'\left(\bar{\bar{s}}\right)\bar{h}+\frac{\int_a^{\tilde{t}}C_s\left(\bar{\bar{s}},t\right)f\left(t\right)dt}{\int_a^{\tilde{t}}f\left(t\right)dt}\right]=0 \tag{41}$$

$$\Rightarrow p'\left(\bar{\bar{s}}\right)\bar{h}+\frac{\int_a^{\tilde{t}}C_s\left(\bar{\bar{s}},t\right)f\left(t\right)dt}{\int_a^{\tilde{t}}f\left(t\right)dt}=0$$

Note that the second term equals the mean of the derivative of the private cost, given that the values of time are in the interval $\left[a,\tilde{t}\right]$. Denote this by $x\left[C_s\left(s,t\right)\right]$ The question is how this second term relates to the left-hand side of (13). Intuitively, given that we take the mean only over 'small' values of time it will be smaller than the mean over the whole interval of values of time. This is shown in Figure 5. 6. In this figure we find the derivative of the expected harm, of the private costs for the lowest, the highest and the average value of time and of the private costs if the values of time are in the interval $\left[a,\tilde{t}\right]$.

Figure 5. 6: Optimal speed limit under imperfect compliance



We see that the standard if there is enforcement, $\overline{\overline{s}}_{enf}$ is lower than the standard if people comply, $\overline{s}_{pc}$. Remember that in our base scenario people with a low value of time, $t < E[t]$, drive too fast, while others with a high value of time, $t > E[t]$ had to drive too slowly. Given an optimal fine and probability of detection, people with a high value of time, $t > \tilde{t}(j) > E[t]$ will violate the speed limit and pay the fine. This is socially optimal. Hence we are left with relatively more people who drive too fast than people who drive too slowly. Hence it is optimal to lower the speed limit. Note that allowing for the possibility of speeding – not complying – improves the performance of regulation.

6. NUMERICAL ILLUSTRATION

We illustrate the model with a numerical example. We consider three types of roads; this is urban roads, interurban roads and highways. This division is based on the current speed limits, which are 120 km/h for highways, 90 km/h for interurban roads and 50 km/h for urban roads. Using GAMS, we calculate the private and socially optimal levels of speed and activity and the levels of speed and activity under the different instruments.

We first calculate the private optimal speed and activity by maximising expression (1). In this illustration, the private cost per kilometre, $C(s,t)$ equals the sum of the resource cost, the fuel cost and the time cost. The resource cost comprises the purchase cost, the insurance, maintenance, etc. We assume that it is independent of the level of speed and equal[92] to 0.23551 euro/km. The fuel cost depends on the fuel price and the fuel use. Both elements depend on the type of fuel. We assume that 59.4% of the cars drive on gasoline and 40.6% on diesel[93]. The price of diesel equals 0.811 €/litre, the price of gasoline equals 1.068 €/litre[94]. The fuel use depends on the fuel type and the speed. Hence we use a different function depending on the fuel and the road type. The functions are given in Table 5. 2 where s is the speed in km/h.

Table 5. 2: Fuel use

Fuel	Speed range	Fuel use (l/km)
Diesel	10-130 km/h	$0.1377779 - 0.00242356s + 0.000016279s^2$
Gasoline	10-60 km/h (urban)	$0.92027s^{-0.583}$
	80-130 km/h (interurban +highway)	$0.0006365s + 0.0395757$

MEET project (1998), International Energy Agency (2002)

The time cost equals the value of time divided by the level of speed. We consider three values of time corresponding with three types of persons, namely others$\left(t_o = € \text{ 4.75, 71\% of population}\right)$[95], commuters$\left(t_c = € \text{ 6.90, 23\% of population}\right)$ and businessmen $\left(t_b = € \text{ 23.87, 6\% of population}\right)$. The utility is a simple 2-level Constant Elasticity of Substitution (CES) function (Keller, 1976). We assume that

---

[92] Own calculations based on De Borger and Proost (1997)

[93] Ministry of Traffic and Infrastructure (2000)

[94] Ministry of Economic Affairs (2001)

[95] Own calculations based on Gunn et al (1997) and Hubert and Toint (2002)

people obtain utility from two goods, transport (ac) and 'other goods' (x). The utility[96] is then given by

$$U=\left(a^{1/s}ac^{s-1/s}+\left(1-a\right)^{1/s}x^{s-1/s}\right)^{s/s-1} \qquad (42)$$

In expression (42), the $a's$ are the share parameters that indicate the share of each utility component in the overall utility. We take a equal to 0.12[97]. The s 's are the elasticity's of substitution. They capture the subjective preferences of the consumer. They indicate how much the consumer is willing to give up of one good in order to receive one more unit of the other good, while keeping his utility level constant. We take s equal to 0.5. The private optimum can be found in the second column of Table 5. 4 for the urban roads, Table 5. 5 for the interurban roads and Table 5. 6 for the highway. We find that the levels of speed are increasing and that activity levels are decreasing in the value of time. Note that we have restricted the speed on urban roads to maximal 70 km/hours and that, given that the cost are the same, people want to drive the same amount and at the same speed on interurban roads as on highways.

The socially optimal levels of speed and activity are calculated by maximising the utility taking into account the private cost and the expected accident cost[98]. The expected accident cost equals the harm times the accident risk. The harm depends on the severity of the accident. We consider three types[99] of accidents, accidents with only lightly injured; accidents with severely injured and fatal accidents. The accident costs of the different types are listed in Table 5. 3. Using data from the BIVV(2000), we calculate the accident risks per km. The result is given in Table 5. 3.

---

[96] We assume that the price of 'other goods' equals one. Using the budget constraint, $y=C(s,t)\cdot ac+1\cdot x$, we can then write (42) as a function of only the activity level, ac .

[97] a and s are taken from Proost et al (1999)

[98] Expression (5) in the theoretical framework.

[99] For the moment, we do not take into account accidents with only material damage. If these accidents are also included, the accident costs will rise and the socially optimal speeds will decrease. The accident costs are based on Schwab et al (1995).

Table 5. 3: Accident cost and accident risk

	Cost of accident (€)	Accident risk per km		
		Urban	Interurban	Highway
Light	101.028	$9.57 \cdot 10^{-7}$	$7.83 \cdot 10^{-7}$	$1.97 \cdot 10^{-7}$
Serious	1.358.830	$1.13 \cdot 10^{-7}$	$1.76 \cdot 10^{-7}$	$0.39 \cdot 10^{-7}$
Fatal	2.103.964	$0.13 \cdot 10^{-7}$	$2.80 \cdot 10^{-7}$	$0.08 \cdot 10^{-7}$

Own calculations based on Schwab et al (1995), BIVV (2000)

In the calculation we take into account the influence of speed on the accident risk[100]. The socially optimal level of speed is listed in the first column of Table 5. 4, Table 5. 5 and Table 5. 6 respectively. As predicted the social level of speed is increasing in the value of time and smaller than the private optimal levels of speed. The level of speed and activity on highways are higher than on interurban roads. Given that the private costs are the same; this is due to the difference in accident costs. This is reflected in Table 5. 3 where the accident risk on interurban roads is higher for all types of accidents. Some argue that not only the speed level but also the variance is an important factor in the probability of an accident. If we take this into account, the differences in speed between the user types would be smaller (Rietveld et al, 1998b). The socially optimal activity level is, as predicted, lower than the private optimum.

To calculate the levels of speed under strict liability, we assume that the level of assets, y equals 100.000 euro and that the probability of suit, q equals 0.8. The results are given in the third column of Table 5. 4, Table 5. 5 and Table 5. 6 respectively. Given that strict liability is diluted, the levels of speed and activity under liability are higher than the socially optimal levels but lower than the private optimal levels.

---

[100] Elvik et al (2000) provides a function which gives the effect of a change in speed on the accident risk: $\text{effect on accident risk} = 1\text{-}\left(\frac{\text{speed}}{\text{current speed}}\right)^{pr}$ with pr equal to 4 for fatal accidents, 3 for accidents with serious injuries, and 2 for accidents with light injuries.

We also calculate the level of regulation. The speed limits listed in the fourth column of Table 5. 4, Table 5. 5 and Table 5. 6 make that the business people have to drive too slowly, while the others drive too fast compared to the social optimum. Notice that the speed limits almost equal the socially optimal solution for the commuters. Given the large proportion of ‘other’ we could have expected that the regulation would be closer to their optimal level of speed. Since this would be far too low for the business people a correction is made for their high vale of time. If we compare with the optimal number of kilometres given that speed is regulated we see that all drive too much because they do not take into account the accident costs. If we compare with the socially optimal activity levels we see that the ‘others’ and the ‘commuters’ drive more, while the ‘business’ drive less. However, the activity levels listed in the first column of the tables are optimal given that speed is socially optimal and under regulation this is not the case.

Next, we calculate the level of speed and activity under a km tax and state the results in the first column of the second row of Table 5. 4, Table 5. 5 and Table 5. 6. Given that the tax does not influence the speed, we find that the optimal speed under a km tax equals the private optimal speed. We find a tax equal to 0.221 euro/km for urban roads, 0.139 euro/km for interurban roads and 0.015 euro/km for highways. If we compare the levels of activity under the tax with the optimal levels, we see that this tax is too high for the ‘commuters’ and the ‘others’ and too low for the ‘business’ on the highway and the interurban roads. Given that people all drive at the same speed on interurban roads, the uniformity is not a problem and people drive the optimal amount of kilometres given their speed.

We also looked at three combinations of instruments; this is the joint use of a km tax and strict liability, of a km tax and regulation and of regulation and strict liability. The results can be found in the last three columns of the second row of Table 5. 4, Table 5. 5 and Table 5. 6 respectively. Under a km tax and strict liability, the levels of speed are the same as under strict liability used alone. By adding the tax we can bring the activity levels closer to the social optimum than under strict liability alone. Note that, because strict liability makes that part of the accident cost is already internalised, the taxes are lower than if only a km tax is used. The joint use of regulation and a km tax makes that people drive at the speed limit and, again, that activity levels are closer to the optimum than if regulation is used alone. Under regulation and strict liability, the speed limit is higher than if regulation is used alone. The 'others' and the 'commuters' drive slower than the speed limit on the highways and on the urban roads. On the interurban roads, only the 'others' drive more slowly. The activity level is again closer to the social optimum, but still too high.

Note that the levels of speed and activity we obtain are realistic. We find speed levels between 59 and 144 km/h. In Vlaams Brabant (a province of Belgium), the actual speeds ranged between 21 km/h and 131 km/h. The very low minimum speed was due to congestion[101]. The calculated activity levels lie between 10.165 km and 15.174 km/year. In 2003 the average number of km driven per year in Belgium equals 15.039 km[102]. This seems to suggest that our model, simple as it is, leads to realistic results.

In a next stage, given the levels of speed and activity above, we calculate the welfare losses under the different instruments. In the last rows of Table 5. 4, Table 5. 5 and Table 5. 6 we represent the welfare losses if people drive at their private optimal speed and of each measure for the different roads, taking into account the distribution of values of time.

---

[101] Vanlaar, W. (2000)

[102] FPS Economy (2005)

Table 5. 4: Numerical illustration – urban roads

	Social		Private		Strict Liability		Regulation	
	s	ac	s	ac	s	ac	s	ac
Commuters	47	12.050	70	14.483	56	12.565	46	13.246
Business	64	9.392	70	11.089	70	9.982	46	9.516
Others	43	12.679	70	15.140	51	13.150	46	14.047
Welfare Losses (€/Driver)	0		-2.694		-243		-222	

	Tax t=0.221€/km		Tax + Strict Liability t=0.046€/km		Tax + Regulation t=0.086€/km		Regulation+Strict Liability limit = 70 km/h	
	s	ac	s	ac	s	ac	s	ac
Commuters	70	11.310	56	11.972	46	12.049	56	12.614
Business	70	9.356	70	9.654	46	8.991	70	9.955
Others	70	11.641	51	12.483	46	12.663	51	13.209
Welfare Losses (€/Driver)	-1.771		-213		-92		-248	

Own calculations

Table 5. 5: Numerical illustration – interurban roads

	Social		Private		Strict Liability		Regulation	
	s	ac	s	ac	s	ac	s	ac
Commuters	60	13.400	101	14.683	71	14.683	59	14.102
Business	84	10.639	144	12.405	104	12.405	59	10.493
Others	54	14.054	91	15.174	91	15.174	59	14.835
Welfare Losses (€/Driver)			-2.345		-182		-127	

	Tax t=0.139€/km		Tax + Strict Liability t=0.027€/km		Tax + Regulation t=0.040€/km		Regulation+Strict Liability limit = 71 km/h	
	s	ac	s	ac	s	ac	s	ac
Commuters	101	12.376	71	13.322	59	13.399	71	13.855
Business	144	10.860	104	10.968	59	10.165	71	10.785
Others	91	12.683	64	13.860	59	14.033	64	14.453
Welfare Losses (€/Driver)	-1.965		-169		-92		-167	

Own calculations

Table 5. 6: Numerical illustration – highway

	Social		Private		Strict Liability		Regulation	
	s	ac	s	ac	s	ac	s	ac
Commuters	89	14.396	101	14.683	94	14.501	87	14.633
Business	127	11.996	144	12.405	135	12.166	87	11.667
Others	80	14.925	91	15.174	84	15.013	87	15.171
Welfare Losses (€/Driver)	0		-69		-11		-76	

	Tax t=0.015€/km		Tax + Strict Liability t=0.005€/km		Tax + Regulation t=0.012€/km		Regulation+Strict Liability limit = 130 km/h	
	s	ac	s	ac	s	ac	s	ac
Commuters	101	14.375	94	14.397	87	14.395	94	14.586
Business	144	12.209	135	12.101	87	11.536	130	12.218
Others	91	14.838	84	14.898	87	14.909	84	15.100
Welfare Losses (€/Driver)	-64		-10		-72		-10	

Own calculations

If we look at the total welfare losses, we see that for the interurban and urban roads the losses are the smallest under regulation and a km tax and the highest, except for the private optimum, under a tax used alone. For the highway the losses are the smallest under a tax and strict liability[103] and the highest under regulation. Remark that the ordering of the measures depends on the assumptions made. Note that adding an instrument does not necessarily increases welfare. Regulation on its own, for example, performs better than the joint use of regulation and strict liability on interurban and urban roads.

We perform a sensitivity analysis to see how the results change under different assumptions. In the base case we assumed that $y = 100{,}000$ and $q = 0.8$ .We find that if the level of assets, *y*, or the probability of conviction, *q*, is low[104], tax and regulation is still preferred. However, if the probability of conviction is one, strict liability alone is preferred on all road types. If the value of harm, *h*, is only half of the values of the base scenario, we again prefer the km tax and regulation on the interurban and urban roads. On the highway, strict liability is then preferred. Since diesel cars travel relatively more kilometres, we change the proportion of diesel versus gasoline cars and find again that a tax and regulation is preferred on interurban and urban roads and a tax and strict liability is favoured on highways. If there are no business people on the road, it makes sense that regulation and a km tax is preferred on all road types. The values of time are then more concentrated around the mean. If the values of time are not concentrated, for example if we have only business people and others, strict liability and a km tax will be favoured on all road types.

7. CONCLUSION

In this paper we consider three instruments to promote traffic safety: strict liability, regulation and a kilometre tax. We assume that the expected accident cost depends on

---

[103] The difference between a tax + strict liability and regulation + strict liability is situated after the comma. Note that Verhoef et al (2004) find that regulation (a minimum speed limit) + a tax is optimal on highways.

[104] $y = 50{,}000$ or $q = 0.1$

the level of speed and the number of kilometres one drives. We show that in a setting of unilateral accidents in which only one party has losses government intervention is needed; otherwise people drive too fast and too much.

We start with the analysis of strict liability. We find that because of the judgement proof problem and/or because the probability of being held liable does not equal one, strict liability does not work perfectly. People drive too much and too fast. Regulation does not lead to the optimal solution because the government lacks information. It sets a uniform speed limit while the optimum differs between people; hence some people drive too fast and others too slowly. The activity level is not directly influenced under regulation, hence people drive too much. The kilometre tax used alone does not control the level of speed and since it is set uniform it will not lead to the socially optimal activity level either. Joint use can perform better but will, in general, not lead to the socially optimal solution. Which instrument performs best depends on a number of factors such as the harm done, the assets of the driver, the distribution of the value of time and the performance of strict liability.

We illustrated this for Belgium by means of a numerical application. The analysis showed that for urban and interurban roads the best policy is the combination of a speed limit and a km tax. Note that the calculated speed limit for urban roads (46km/h) is close to the actual speed limit. For interurban roads the calculated speed limit (59 km/h) is much lower than the actual speed limit (90 km/h). Hence our analysis suggests that, if we only consider the private cost and the accident costs, the speed limit on interurban roads in Belgium should decrease. For highways, we found that strict liability and a km tax performed the best. This would suggest the abolishment of speed limits on highways, which is the case on some highways in Germany.

In the basic analysis we assume that people comply with the regulation. This is of course not realistic. We relax this assumption and consider the optimal enforcement problem. We calculate the optimal fine, probability of detection and the speed limit. We find that the speed limit is even lower if there is no full compliance and that allowing for non-compliance increases the performance of regulation.

This is a first attempt to model traffic safety. Many extensions and improvements to the theoretical framework and the exercise are possible.

An important extension would be the incorporation of the costs of the measures. In determining the welfare losses of different measures we should not only look how ‘close’ the measure brings us to the optimum, but also at its costs. In the analysis up to now we only considered the costs of enforcement. However strict liability and a kilometre tax also have their costs. Think for example of the cost of the lawyers, courts, infrastructure,… The cost of strict liability is higher per case, but the costs only occur if there is an accident. The cost of enforcement of regulation is lower, but there will be more cases of violating the speed limit than there are accidents. The costs of imposing a km tax are still very uncertain. Therefore we can not predict how including these costs would influence the relative performance of the measures.

Another possible extension would be the inclusion of bilateral accidents; this is of accidents in which both parties influence the probability of an accident and both have losses. This would increase the realism of the model but would also make it more complicated. The behaviour of one party would depend on the behaviour of the other party and we should consider different liability rules and their problems. We can not say ex ante how this would influence the analysis.

Further it would be useful to consider risk averse drivers and insurance. Insurance is of particular interest since it influences the expected cost under any liability rule of people. The role of the liability rule is not to influence directly the choice of speed or activity, but to determine whose insurance pays for the accident costs. The speed and activity level will then depend on the power of the insurance company to influence the driver.

Up to now we only looked at accidents, a further extension could exist of including other external costs such as congestion, pollution, noise,…

With respect to the empirical illustration it is clear that we could incorporate the theoretical analysis of enforcement into the exercise. This would emphasise the need to lower the speed limits on interurban roads.

Appendix 5A: Proofs Social Optimum

For a given harm, $\bar{h}$, the socially optimal speed level is an increasing function of the value of time, $s_t^*\left(t,\bar{h}\right) > 0$.

Proof: if we differentiate (6) with respect to t, we obtain

$$\begin{aligned} & C_{ss}(s,t)s'(t) + C_{st}(s,t) = -p''(s)\cdot\bar{h}\cdot s'(t) \\ & \Leftrightarrow C_{st}(s,t) = \left[-p''(s)\cdot\bar{h} - C_{ss}(s,t)\right]\cdot s'(t) \\ & \Leftrightarrow s'(t) = \frac{C_{st}(s,t)}{-p''(s)\cdot\bar{h} - C_{ss}(s,t)} > 0 \end{aligned} \tag{C1}$$

given $C_{st} < 0$. ¦

For a given value of time, $\bar{t}$, the socially optimal speed level is a decreasing function of harm, $s_h^*\left(\bar{t},h\right) < 0$.

Proof: If we differentiate (6) with respect to h, we get

$$\begin{aligned} & C_{ss}(s,\bar{t})s'(h) = -p'(s)\cdot 1 - p''(s)\cdot h\cdot s'(h) \\ & \Leftrightarrow p'(s) = \left[-p''(s)\cdot h - C_{ss}(s,\bar{t})\right]\cdot s'(h) \\ & \Leftrightarrow s'(h) = \frac{p'(s)}{-p''(s)\cdot\bar{h} - C_{ss}(s,\bar{t})} > 0 \end{aligned} \tag{C2}$$

¦

For a given harm, $\bar{h}$, the socially optimal activity level decreases in the value of time, $ac'(t) < 0$.

Proof: If we differentiate (7) with respect to the value of time, t, we obtain

$$\begin{aligned} & \frac{U''(ac)\cdot ac'(t)}{l} = C_t(s,t) + \left[p'(s)\cdot\bar{h} + C_s(s,t)\right]s'(t) \\ & \Leftrightarrow ac'(t) = l\ \frac{C_t(s,t) + \left[p'(s)\cdot\bar{h} + C_s(s,t)\right]s'(t)}{U''(ac)} < 0 \end{aligned} \tag{C3}$$

¦

For a given value of time, $\overline{t}$, the socially optimal activity level decreases in the level of harm, $ac'(h) < 0$

Proof: If we differentiate (7) with respect to the level of harm, h, we get

$$\begin{aligned} &\frac{U''(ac)\cdot ac'(h)}{l} = C_s(s,\overline{t})\cdot s'(h) + p(s) + p'(s)\cdot h\cdot s'(h) \\ &\Leftrightarrow ac'(h) = l\,\frac{C_s(s,\overline{t})\cdot s'(h) + p(s) + p'(s)\cdot h\cdot s'(h)}{U''(ac)} < 0 \end{aligned} \tag{C4}$$

¦

Appendix 5B: Joint use.

(1) Regulation and strict liability

Proposition:

If the incentives under liability alone are diluted by incomplete conviction or the judgement proof problem, three cases can arise under joint use of regulation and strict liability:

a) First of all, joint use could be optimal. Under joint use the maximum level of speed, $\overline{s}_{ju}$, is higher than the level of regulation, $\overline{s}$, if regulation is used alone. However it is lower than the first-best level of speed for those parties with the highest value of time, $s^*\left(b,h\right)$.

$$s^*\left(b,\overline{h}\right) > \overline{s}_{ju} > \overline{s} \qquad \text{(D1)}$$

Furthermore, in this case some parties are induced by liability to lower their speed more than required. A sufficient condition for (D1) to hold is

$$s_L\left(a,\overline{h}\right) < \overline{s} \qquad \text{(D2)}$$

Or equivalently, strict liability causes enough tempering of speed such that the level of speed under strict liability for the driver with the lowest value of time is lower than the speed limit. In other words, the incentive for moderating speed is not excessively diluted ($q > \tilde{q}(y)$ and $y > \tilde{y}(q)$).

b) Secondly, regulation alone could be optimal. The optimal regulatory standard then equals the optimal standard where regulation is used alone, that is

$$\overline{s}_{ju} = \overline{s} \qquad \text{(D3)}$$

In this case, no party will drive slower than s^{**}. This is the result if strict liability does not work well. ($q < \tilde{q}(y)$ and $y < \tilde{y}(q)$) or if the variability amongst parties is sufficiently small (distribution of *t* is relatively concentrated around the mean).

c) Thirdly, strict liability on its own could be optimal. In that case the standard is set equal or higher than the level of speed of the person with the highest value of time under strict liability alone, that is

$$\overline{s}_{ju} \geq s_L\left(b,\overline{h}\right) \qquad \text{(D4)}$$

In this case, everyone will drive at his optimal level of speed under strict liability. This is the result if liability is not much diluted ($q > \tilde{\tilde{q}}(y) > \tilde{q}(y)$ and $y > \tilde{\tilde{y}}(q) > \tilde{y}(q)$) or if the variability of the values of time is large.

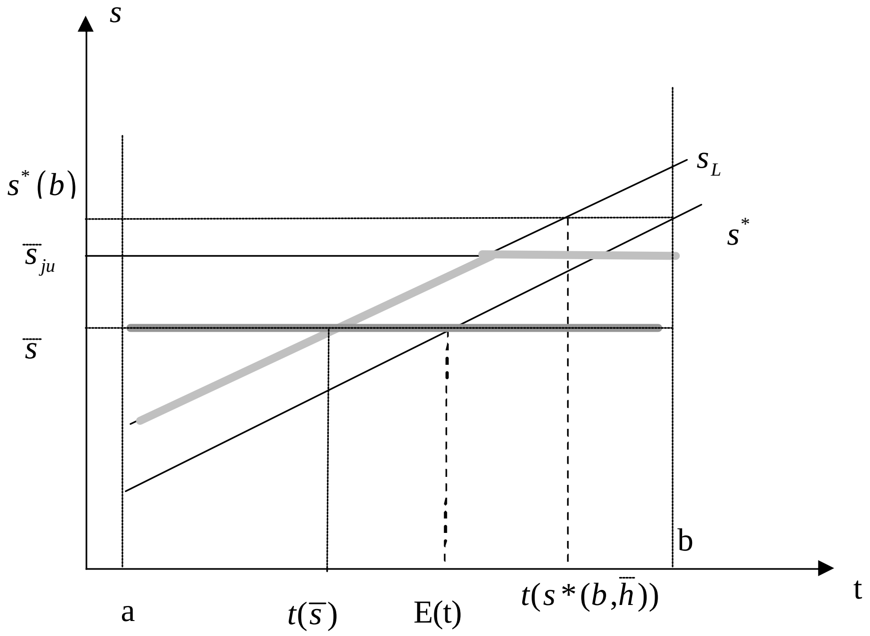
Proof

In this proof we focus on the level of speed since speed is directly influenced by both regulation and strict liability. The activity level is not directly influenced by the speed limit, but is mainly determined by strict liability. We already proofed that, if liability is diluted, this would lead to an excessive activity level. To make things more clear we first give an intuitive proof of the proposition and next give the formal proof.

Intuitive Proof:

(a) To understand why $\overline{s}_{ju}$ may be larger than $\overline{s}$, consider Figure 5. 7 and condition (D2) $s_L\left(a,\overline{h}\right) < \overline{s}$, which means that some parties drive more slowly than the speed limit because of liability. The reason why this condition implies $\overline{s}_{ju} > \overline{s}$ is that when regulation is used alone, increasing the standard above $\overline{s}$ was not worthwhile, because it made all parties drive faster. Here it only results in people with $t > t\left(\overline{s}\right)$ driving faster; parties with a low value of time are induced to lower speed levels than $\overline{s}$ by strict liability. This means that strict liability takes up some of the welfare loss resulting from raising the maximum speed.

Figure 5. 7: Optimal joint use: case where some parties drive slower than the speed limit



On the other hand, to understand why $\overline{s}_{ju} < s^*\left(b,\overline{h}\right)$, suppose that $\overline{s}_{ju} = s^*\left(b,\overline{h}\right)$. All people with $t < t\left(s^*\left(b,\overline{h}\right)\right)$, will drive at $s_L\left(t,\overline{h}\right)$, the others will drive at $\overline{s}_{ju}$. However these people, except for *t=b*, drive too fast compared to the optimum. Observe that lowering the level of speed from the level $s^*\left(b\right)$ does not lead to a first order change in expected social cost for people with *t=b,* but it leads to a reduction of the social cost for people with $t \geq t\left(s^*\left(b,\overline{h}\right)\right)$.

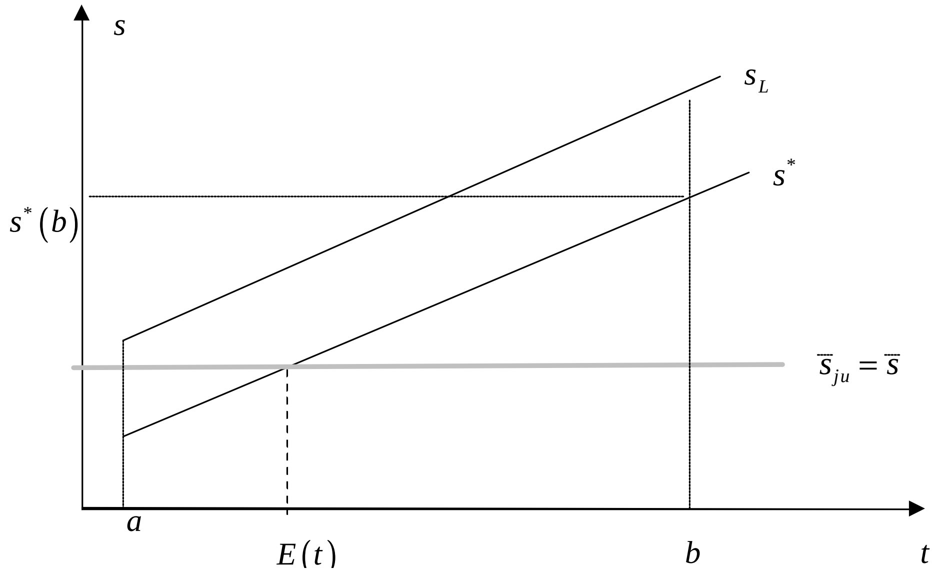
In the formal proof we will show that $\overline{s}_{ju}$ is determined by

$$\left[p'\left(s\right)\overline{h} + \frac{\int_{t(s)}^{b} C_s\left(s,t\right) f\left(t\right) dt}{\int_{t(s)}^{b} f\left(t\right) dt}\right] = 0 \qquad \text{(D5)}$$

This can be interpreted as follows: the expected marginal cost of (reducing) the speed level equals the reduction in harm, where expectation is over only those parties who are not affected by strict liability and thus are affected by the maximum speed level. Note that (D5) is the analogue of (13).

(b) It is evident from Figure 5. 8 why this case arises if the incentives created by strict liability are too much diluted: then the incentive to lower one's speed created by strict liability is too weak to take up any of the slack due to raising the speed limit above $\overline{s}$. It is therefore best to leave the standard at $\overline{s}$. This is a case in which regulation should be used alone, strict liability has nothing to add but cost. If the variability of the values of time is low, regulation will be optimal. Consider the extreme case where there is only one value of time. Regulation will then lead to the social optimum.

Figure 5. 8: Optimal joint use: case where all parties drive at the maximum speed level.



(c) If liability works perfectly (q=1, $y \geq \overline{h}$), it is clear that regulation has nothing to add. If liability works close to perfect, it could be optimal to use it as the only instrument. If the variability of the value of time is high, it could also be optimal to use strict liability alone, since this measure takes into account the individual values of time, while regulation only looks at the average.

Formal Proof:

We first prove part a), then b) and finally c).

Proof of part a

The proof of this part consists of four steps:

In **(i)**: $\bar{s} \le \bar{s}_{ju} \le s^*\left(b,\bar{h}\right)$

In **(ii)**: if $\bar{s} \le \bar{s}_{ju}$ then $s_L\left(a,\bar{h}\right) < \bar{s}_{ju}$

In **(iii)**: $\bar{s}_{ju} < s^*\left(b,\bar{h}\right)$ and $\left[p'(s)\bar{h} + \dfrac{\int_{t(s)}^{b} C_s(s,t)\, f(t)\,dt}{\int_{t(s)}^{b} f(t)\,dt} \right] = 0$

In **(iv)**: if $s_L\left(a,\bar{h}\right) < \bar{s}$ then $\bar{s} \le \bar{s}_{ju}$

(i) $\bar{s}_{ju}$ must lie between $\bar{s}$ and $s^*\left(b,\bar{h}\right)$.

It is easy to verify that for every t, the expected social costs are lower at $\bar{s} = s^*\left(b,\bar{h}\right)$, than at a higher speed limit. Under $\bar{s} = s^*\left(b,\bar{h}\right)$, all parties except people with a value of time equal to b, drive too fast. Under $\bar{s} > s^*\left(b,\bar{h}\right)$ even parties with a value of time equal to b drive too fast. Hence, $\bar{s}_{ju} \le s^*\left(b,\bar{h}\right)$.

To show that $\bar{s} \le \bar{s}_{ju}$, assume otherwise $\bar{s} > \bar{s}_{ju}$. Let SC(s;r) be the expected social cost, when regulation is used alone and let SC(s;rl) be the expected social cost when regulation is used jointly with liability. Then for any $s_1 > s_2$, we claim that the difference in social cost when regulation is used alone is larger than the difference when they are jointly employed.

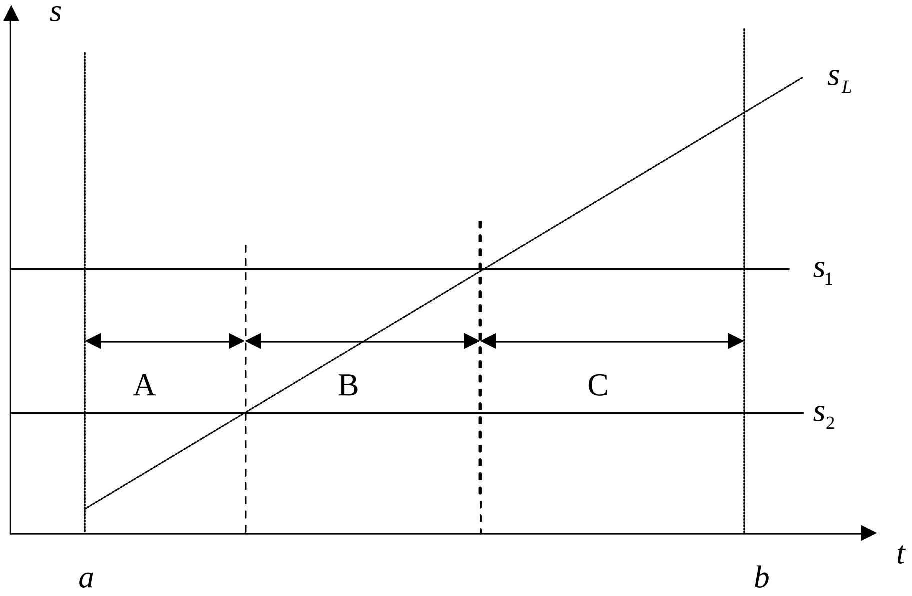
$$SC(s_1;r) - SC(s_2;r) \ge SC(s_1;rl) - SC(s_2;rl) \qquad \text{(D6)}$$

This can be shown by demonstrating that the corresponding weak inequality in social costs holds for given $\bar{h}$ and every t:

$$\left[C(s_1,t)+p(s_1)\bar{h}\right]-\left[C(s_2,t)+p(s_2)\bar{h}\right]\geq$$
$$\left[C\left(min\left\{s_1,s_L\left(t,\bar{h}\right)\right\},t\right)+p\left(min\left\{s_1,s_L\left(t,\bar{h}\right)\right\}\right)\bar{h}\right]-\left[C\left(min\left\{s_2,s_L\left(t,\bar{h}\right)\right\},t\right)+p\left(min\left\{s_2,s_L\left(t,\bar{h}\right)\right\}\right)\bar{h}\right] \quad \text{(D7)}$$

We can see this on Figure 5. 9.

Figure 5. 9: Joint use versus regulation



The regions A, B and C show the different possible relations that may hold among s_1, s_2 and $s_L\left(t,\bar{h}\right)$. For t in region C, (D7) holds with equality for the parties will act identical under regulation used alone as under joint use. For t in region B, parties will drop their level of speed from s_1 to s_2 if regulation is used alone. Under joint use, they will only drop their speed from $s_L\left(t,\bar{h}\right)$ to s_2. (D7) becomes

$$\left[C(s_1,t)+p(s_1)\bar{h}\right]-\left[C(s_2,t)+p(s_2)\bar{h}\right]\geq\left[C\left(s_L\left(t,\bar{h}\right),t\right)+p\left(s_L\left(t,\bar{h}\right)\right)\bar{h}\right]-\left[C(s_2,t)+p(s_2)\bar{h}\right]$$
$$\Rightarrow\left[C(s_1,t)+p(s_1)\bar{h}\right]\geq\left[C\left(s_L\left(t,\bar{h}\right),t\right)+p\left(s_L\left(t,\bar{h}\right)\right)\bar{h}\right]$$

However, this holds with strict inequality since the expected social cost is convex in the level of speed and for t in region B, $s_1\left(t,\bar{h}\right)>s_L\left(t,\bar{h}\right)>s^*\left(t,\bar{h}\right)$. In region A, (D7) also holds with strict inequality since, under regulation on its own, the level of speed drops from s_1 to s_2. Moreover, the expected social costs are convex and in for *t* in region A, $s_1\left(t,\overline{h}\right) > s_2\left(t,\overline{h}\right) > s^*\left(t,\overline{h}\right)$. The expected social costs are thus lower at s_2 than at s_1. Hence, the difference is positive. Under joint use, the level of speed stays at $s_L\left(t,\overline{h}\right)$; hence, the expected social costs do not change and the difference is zero. Thus, since the difference in regulation is positive and the difference in joint use is zero, the strict inequality holds.

If $\overline{s} > \overline{s}_{ju}$, we conclude out of (D6) that

$$SC\left(\overline{s};r\right) - SC\left(\overline{s}_{ju};r\right) \geq SC\left(\overline{s};rl\right) - SC\left(\overline{s}_{ju};rl\right) \tag{D8}$$

As $\overline{s}_{ju}$ minimises $SC\left(s;rl\right)$ over s, we know that

$$SC\left(\overline{s};rl\right) - SC\left(\overline{s}_{ju};rl\right) \geq 0 \tag{D9}$$

Hence

$$SC\left(\overline{s};r\right) - SC\left(\overline{s}_{ju};r\right) \geq 0 \tag{D10}$$

which contradicts the fact that $\overline{s}$ is the unique minimum of minimising $SC\left(s;r\right)$ over s. We conclude that $\overline{s} \leq \overline{s}_{ju}$.

(ii) **We prove that $\overline{s}_{ju} > \overline{s}$ implies that some parties will drive slower than $\overline{s}_{ju}$ due to liability, this is, $s_L\left(a,\overline{h}\right) < \overline{s}_{ju}$.**

Suppose otherwise, $s_L\left(a,\overline{h}\right) \geq \overline{s}_{ju}$. Then for $s \leq \overline{s}_{ju}$, the second term in (25) becomes relevant. In this case, no one will be induced by liability to drive slower; hence regulation will be used on its own. The regulator will $\underset{s \leq s_L\left(a,\overline{h}\right)}{min} \int_a^b \left[C\left(s,t\right) + p\left(s\right)\overline{h}\right] f\left(t\right) dt$.

Since this term has a unique solution over all s at $\overline{s}$ and since $\overline{s}_{ju} > \overline{s}$, the term must have a unique minimum over $s \leq \overline{s}_{ju}$ at $\overline{s}$. However, this means that $\overline{s}_{ju} > \overline{s}$, but this contradicts our starting point that $\overline{s}_{ju} > \overline{s}$.

(iii) **Here we prove that $\bar{s}_{ju} > \bar{s}$ implies $\bar{s}_{ju} < s^*\left(b,\bar{h}\right)$ and that $\bar{s}_{ju}$ is determined by the first order condition (D5). This is**

$$\left[p'(s)\bar{h} + \frac{\int_{t(s)}^{b} C_s(s,t)\, f(t)\,dt}{\int_{t(s)}^{b} f(t)\,dt} \right] = 0$$

Out of **(ii)** follows that if $\bar{s}_{ju} > \bar{s}$, the regulator will use regulation and liability jointly. Hence, the first term in expression (25) is relevant for all s in the interval properly including $s^*\left(a,\bar{h}\right)$ and $\bar{s}_{ju}$. He will

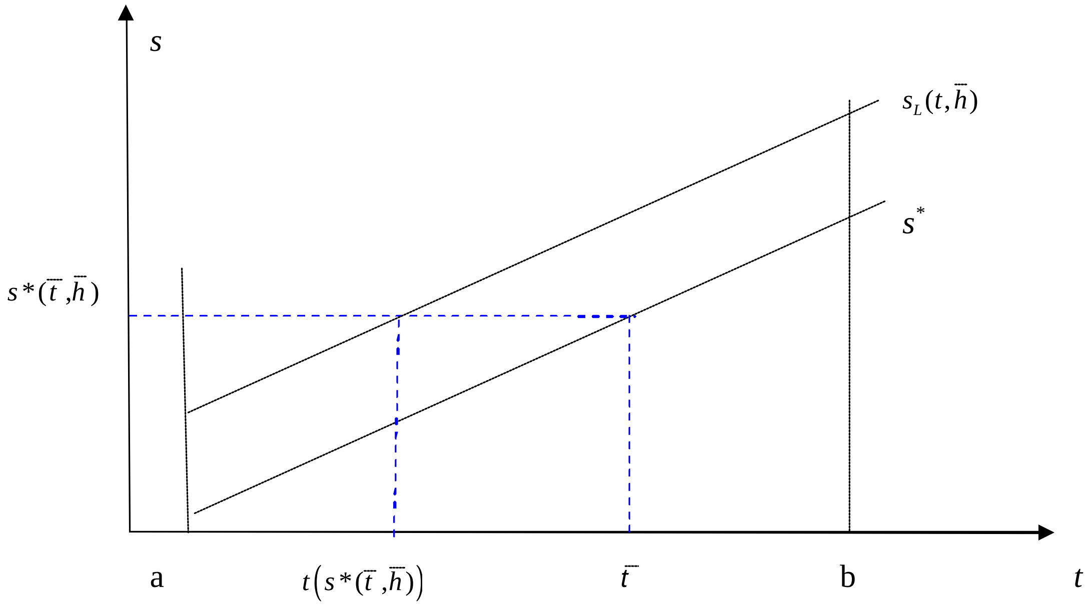
$$\min_{s_L(b,\bar{h}) > \bar{s} > s_L(a,\bar{h})} \left(\int_{a}^{t(s)} \left[C\left(s_L\left(t,\bar{h}\right),t\right) + p\left(s_L\left(t,\bar{h}\right)\right)\bar{h} \right] f(t)\,dt + \int_{t(s)}^{b} \left[C(s,t) + p(s)\bar{h} \right] f(t)\,dt \right)$$

In particular, the first derivative with respect to s, evaluated at $\bar{s}_{ju}$ should be zero. We calculate the first derivative:

$$\int_{t(s)}^{b} \left[C_s(s,t)\, f(t)\, d \right] f(t)\,dt + p(s)\bar{h} \int_{t(s)}^{b} f(t)\,dt \qquad \text{(D11)}$$

From **(i)** we know that $\bar{s}_{ju} \le s^*\left(b,\bar{h}\right)$. For any t such that $s^*\left(t,\bar{h}\right)$ lies in the domain of $t(\ )$, we have $t\left(s^*\left(t,\bar{h}\right)\right) < t$ (see also Figure 5. 10), hence, $t\left(s^*\left(b,\bar{h}\right)\right) < b$ and since $t(\ )$ is increasing in its argument; we know that $\int_{t(s)}^{b} f(t)dt > 0$.

Figure 5. 10: $t\left(s^*\left(t,\bar{h}\right)\right) < t$



Rewriting (D11) we have

$$\int_{t(s)}^{b} f(t)\,dt \left[p'(s)\bar{h} + \frac{\int_{t(s)}^{b} C_s(s,t) f(t)\,dt}{\int_{t(s)}^{b} f(t)\,dt} \right] \tag{D12}$$

(D12) equals zero at s**, hence, $\left[p'(\bar{s}_{ju})\bar{h} + \frac{\int_{t(s)}^{b} C_s(\bar{s}_{ju},t) f(t)\,dt}{\int_{t(s)}^{b} f(t)\,dt} \right] = 0$.

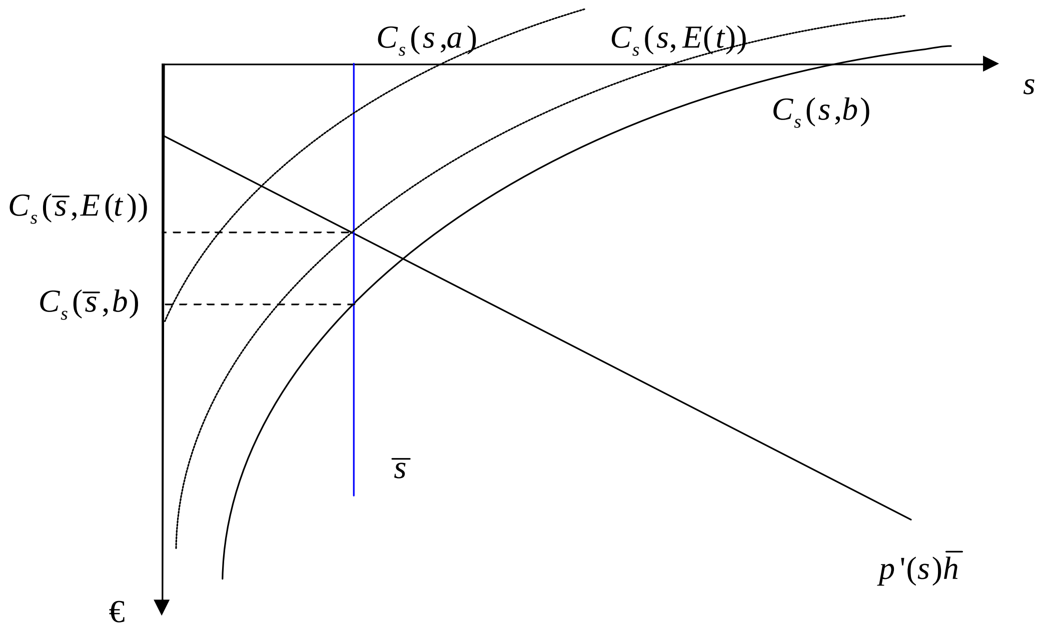
In **(i)** we already showed that $\bar{s}_{ju} \le s^*\left(b,\bar{h}\right)$. To prove that $\bar{s}_{ju} < s^*\left(b,\bar{h}\right)$, we only need to show that $\bar{s}_{ju} \ne s^*\left(b,\bar{h}\right)$. We do this by proving that at $\bar{s}_{ju} = s^*\left(b,\bar{h}\right)$, (D12) does not equal zero.

We know that $t\left(s^*\left(b,\bar{h}\right)\right) < b$, hence $\int_{t\left(s^*\left(b,\bar{h}\right)\right)}^{b} f\left(t\right)dt > 0$. Furthermore observe that (D13) is the mean of the derivative of the private cost, given that the value of time is in the interval [t(s),b].

$$\frac{\int_{t(s)}^{b} C_s\left(s,t\right) f\left(t\right)dt}{\int_{t(s)}^{b} f\left(t\right)dt} \qquad \text{(D13)}$$

(D13) tends to the derivative of the private cost, given a value of time b, if t(s) tends to b. Given Figure 5. 11 observe that (D13) increases if t(s) increases. Thus, if $s = s^*\left(b,\bar{h}\right)$, (D13) $> C_x\left(s^*\left(b,\bar{h}\right),b\right)$ since $t\left(s^*\left(b,\bar{h}\right)\right) < b$. Observe that $C_x\left(s,t\right) + p'\left(s\right)\bar{h} = 0$ for $t=b$ if $s = s^*\left(b,\bar{h}\right)$. Given that (D13) $> C_x\left(s^*\left(b,\bar{h}\right),b\right)$, it follows that the second term in (D12)>0. Since the first term was also positive, it is clear that (D12)>0. Hence (D12) $\neq 0$ when evaluated at $s^*\left(b,\bar{h}\right)$.

Figure 5. 11: (D13)



(iv) If (D2), $s_L\left(a,\overline{h}\right) < \overline{s}_{ju}$ holds, $\overline{s}_{ju} > \overline{s}$.

Suppose otherwise, $\overline{s}_{ju} \leq \overline{s}$. In (i) we proved that $\overline{s}_{ju} \geq \overline{s}$, hence $\overline{s}_{ju} = \overline{s}$. However, suppose (D2) implies that the first term in (25) is relevant at $\overline{s}$. We need only to show that (D12)>0 at $\overline{s}$ to contradict the presumed optimality of $\overline{s}_{ju} = \overline{s}$. Note that from (14) and (6) that $\int_a^b C_s\left(\overline{s},t\right) f\left(t\right)dt + p'\left(s\right)\overline{h}\int_a^b f\left(t\right)dt = 0$. However,(D13)< $\int_a^b C_s\left(\overline{s},t\right) f\left(t\right)dt$, hence $\int_{t(s)}^b C_s\left(\overline{s},t\right) f\left(t\right)dt + p'\left(s\right)\overline{h}\int_{t(s)}^b f\left(t\right)dt > 0$

Remark that (D2) will hold if q and y are sufficiently high, for as q approaches 1 and y sufficiently large, $s_L\left(a,\overline{h}\right)$ will go to $s^*\left(a,\overline{h}\right) < \overline{s}$.

Proof of part b.

(v) If $\overline{s}_{ju}$ equals $\overline{s}$, no one will drive slower than $\overline{s}$.

Otherwise, if $s_L\left(a,\overline{h}\right) < \overline{s}$, which by **(iv)** implies that $\overline{s}_{ju} > \overline{s}$, a contradiction.

(vi) If $s_L\left(a,\overline{h}\right)$ sufficiently high, then $\overline{s}_{ju} = \overline{s}$. This is, if the incentives created by liability are so diluted that adding liability does not change the level of speed, the optimal standard equals the standard if regulation is used alone. In fact, you only use regulation, liability has nothing to add.

Assume the contrary, then it must be possible that $\overline{s}_{ju} > \overline{s}$, for an $s_L\left(a,\overline{h}\right) \geq s^*\left(b,\overline{h}\right)$. But by **(ii)** we know that if $\overline{s}_{ju} > \overline{s}$, then $s_L\left(a,\overline{h}\right) < \overline{s}_{ju}$. Hence, $s_L\left(b,\overline{h}\right) < \overline{s}_{ju}$. This contradicts **(i)**, so that certainly for all $s_L\left(a,\overline{h}\right)$ as high as $s^*\left(b,\overline{h}\right), \overline{s}_{ju} = \overline{s}$.

Remark also that it is clear that as q decreases, so does $s_L\left(a,\overline{h}\right)$ and it tends to the private optimal speed as q tends to zero. Similarly, if y tends to a. Hence if q or y sufficiently small: $\overline{s}_{ju} = \overline{s}$.

If the variability of the values of time is low, regulation will be optimal. Consider the extreme case where there is only one value of time. Regulation will then lead to the social optimum.

Proof of part c.

(vii) $\bar{s}_{ju} \geq s_L\left(b,\bar{h}\right)$

Assume that q=1, $y \geq \bar{h}$, then strict liability works perfectly, that is $s_L\left(t,\bar{h}\right) = s^*\left(a,\bar{h}\right)$ for all t. Since the social cost function is convex and continuous, there exist a level of conviction for a given level of assets $\tilde{q}(y)$ and a level of assets $\tilde{y}(q)$ for a given level of conviction, such that strict liability on its own is preferred.

If there is sufficient variability, strict liability on its own will also be preferred, since it takes into account the variability in t, while regulation only takes into account the average value of time.

(2) Strict liability and a kilometre tax

Under joint use people are strictly liable if an accident happens and they pay a tax on their activity level. Hence the driver maximises his utility, taking into account his private costs, his expected liability costs and the tax.

$$\begin{gathered} \max_{ac,s} U\left(ac\right) \\ s.t.\, ac\left(C\left(s,t\right)+qp\left(s\right)min\left\{\bar{h},y\right\}+tax^t_{jl}\right)+x=y \end{gathered} \tag{D14}$$

The first order conditions with respect to the level of speed are

$$\begin{gathered} -ac\cdot l\cdot\left(C_s\left(s,t\right)+qp'\left(s\right)min\left\{\bar{h},y\right\}\right)=0 \\ \Rightarrow C_s\left(s,t\right)+qp'\left(s\right)min\left\{\bar{h},y\right\}=0 \end{gathered} \tag{D15}$$

This gives the same level of speed as under strict liability used alone, $s_L\left(t,\bar{h}\right)$.

For the driver, the first order condition with respect to the activity level then is

$$\frac{U'\left(ac\right)}{l}=\left(C\left(s_L\left(t,\bar{h}\right),t\right)+qp\left(s_L\left(t,\bar{h}\right)\right)min\left\{\bar{h},y\right\}+tax^t_{jl}\right) \tag{D16}$$

The government maximises the same social welfare as in (11) hence the first order condition looks like

$$\frac{U'(ac)}{l} = \left(C\left(s_L\left(t,\bar{h}\right),t\right) + p\left(s_L\left(t,\bar{h}\right)\right)\bar{h}\right) \tag{D17}$$

Comparing (D17) and (D16), we find that a tax for each value of time and given $\bar{h}$ would equal

$$\begin{aligned} &qp\left(s_L\left(t,\bar{h}\right)\right)min\left\{\bar{h},y\right\} + tax_{jl}^{t} = p\left(s_L\left(t,\bar{h}\right)\right)\bar{h} \\ &\Rightarrow tax_{jl}^{t} = p\left(s_L\left(t,\bar{h}\right)\right)\left[\bar{h} - qp\left(s_L\left(t,\bar{h}\right)\right)\right] \end{aligned} \tag{D18}$$

Given that the government can only set a uniform tax, the tax equals

$$tax_{jl}^{*} = E\left[p\left(s_L\left(t,\bar{h}\right)\right)\left[\bar{h} - qp\left(s_L\left(t,\bar{h}\right)\right)\right]\right] \tag{D19}$$

Again, this will not lead to the socially optimal solution. Substituting (D19) in (D16) gives

$$\begin{aligned} &\frac{U'(ac)}{l} = \left(C\left(s_L\left(t,\bar{h}\right),t\right) + qp\left(s_L\left(t,\bar{h}\right)\right)min\left\{\bar{h},y\right\}\right) + E\left[p\left(s_L\left(t,\bar{h}\right)\right)\left[\bar{h} - qmin\left\{\bar{h},y\right\}\right]\right] \\ &\Rightarrow \frac{U'(ac)}{l} = C\left(s_L\left(t,\bar{h}\right),t\right) + E\left(p\left(s_L\left(t,\bar{h}\right)\right)\right)\bar{h} + qmin\left\{\bar{h},y\right\}\left[p\left(s_L\left(t,\bar{h}\right)\right) - E\left[p\left(s_L\left(t,\bar{h}\right)\right)\right]\right] \end{aligned} \tag{D20}$$

If $E\left[p\left(s_L\left(t,\bar{h}\right)\right)\right] = p\left(s_L\left(t,\bar{h}\right)\right)$, the driver will drive the optimal number of kilometres. If $E\left[p\left(s_L\left(t,\bar{h}\right)\right)\right] > p\left(s_L\left(t,\bar{h}\right)\right)$, the second term of the right-hand side of (D20) will be too large. The last term will correct this partly. If $q\min\left\{y,\bar{h}\right\} = 1$, the activity level will be optimal, if it is larger than 1, the correction will be too large and the driver will drive too little; if it is smaller than 1, the correction will be too small and the activity level too high. The reasoning for $E\left[p\left(s_L\left(t,\bar{h}\right)\right)\right] < p\left(s_L\left(t,\bar{h}\right)\right)$ is analogous. In general, some people will drive too much, others too little.

Conclusions

One of the main causal factors of traffic accidents is the behaviour of people; 85 per cent of all accidents are mainly due to road users' error, 10 percent is attributed to imperfect roadway design and other environmental factors and 5 per cent to vehicle defects (Lonero et al, 1995). In this dissertation I focus on the behaviour of people; more particularly, I focus on their choice of speed/level of care and on the number of kilometres they drive. This choice can be influenced by the use of different instruments such as traffic regulation, liability rules, infrastructural and technical measures, education and sensitisation. The focus of this work lies on regulatory instruments, liability rules and economic instruments. In this concluding chapter I first briefly repeat the main findings of the different chapters, comment on some assumptions and end with some policy guidance.

1. MAIN FINDINGS

We first focused on **regulation**, as it is widely used in traffic. Think of alcohol limits, technical regulation, mandatory seat belts, etc. However, all this regulation needs to be enforced.

The first paper of this dissertation deals with **repeated offenders.** Current practice in Belgium (and most European countries) is that fines for traffic offences are increasing in the level of speed and increasing with the number of previous offences. I start from the empirical fact that there is a positive relationship between previous convictions and the probability of being involved in an accident. The idea behind it is the following: Drivers differ in their skills, risk taking, etc. This makes that drivers differ in their probability to have an accident. This means that, for the same level of speed, the probability of being involved in an accident is higher for an "incapable" driver than for a "capable" driver. The government does not know who the bad drivers are, but previous speeding violations may act as a "signal" for being a bad driver. I state that the offence history gives some information on the type of the driver. I confront two fine structures, both increasing with speed: a uniform fine and a differentiated fine, which depends on the offence history. I do not look for the optimal structure, but merely compare these two systems. The choice between the two systems then depends on different parameters. In order to determine the importance of these parameters, a numerical illustration looked at two things. First, the calculated optimal values for the speeding fines are compared with the existing fines in Belgium. I find that if the Belgian probability of being caught speeding equals 0.9 percent, the current fines approach our optimal fines. Next, I tried to find the critical values of the parameters, which determine the choice between the two fine structures. I find that in most cases and for reasonable assumptions on the current probability of detection, the uniform fine system performs better. The main reason for this result is the weak signalling function of speeding. This seems to suggest that, given the current low probabilities of detection, fines should not depend on the offence history.

The second paper deals with the **political economy of the fine structure for speeding**. In order to increase road safety, the regulating authorities have different monitoring and enforcement strategies to put speed limitations into effect. In general, the public debate emphasises raising the probability of detecting speed violations rather than increasing the fines. This observation conflicts with traditional economic theory prescribing that fines should be set at the highest possible level and that the monitoring effort should be chosen as low as possible, given the costs. In Europe, we see at present large variations in the magnitude of speeding fines and in the probability of detection. Even within countries, traffic safety policies vary between regions. In this chapter we look at the driving forces behind the monitoring and enforcement decisions associated with speed restrictions. We investigate the possible outcomes of the political process depending on the activity and the weight of two interest groups, the vulnerable (cyclists or pedestrians) and the strong road users (car or truck drivers). We show – both theoretically and empirically - that, under acceptable assumptions, vulnerable road users prefer a higher expected fine than the strong road users. The reason is that vulnerable road users carry all the accident losses in our model. The strong road users, on the other hand, prefer a very low expected fine since they have to pay the fines and see none of the benefits associated with an increase in traffic safety. If we focus on the choice between the magnitude of the fine and the inspection probability for a given fixed expected fine, we find that the vulnerable road users prefer a higher fine and a lower inspection frequency than the strong road users. The main reason is that inspection costs are also paid by the vulnerable road users while fines are only paid by the strong road users. Therefore we find that lobby groups can play a role in the setting of current monitoring and enforcement policies. Depending on the weight of the various interest groups, different combinations of the stringency of the fine function and the inspection probability may be optimal for the policy maker.

For **liability rules** we considered one specific case, more particularly bike/car accidents. When we consider the European legislation we find that in many countries a different liability rule applies for accidents between a motorised user and a vulnerable road user than for accidents between motorised users. In general, this is true for countries with a relatively high share of vulnerable road users. Hence we could use the model developed in the second paper to analyse this. I opt here for a different approach. I investigate whether the argument made by policy makers for having these different rules made sense. For example, in Belgium, a rule of negligence applies for accidents between motorised users. On the other hand, only the motorised road user is liable for the accident if the other party involved is a vulnerable road user. The argument made is that a vulnerable road user risks his limbs and life and therefore will be careful even though he is not liable. To check this statement I consider how different liability rules influence the behaviour of cars and vulnerable road users and if the vulnerable road user indeed takes care simply because he might get hurt. I find that there lies some truth in this argument. Because of the risk they take more care than if they would not risk their life. However the incentive is not high enough. Under strict liability the cyclist exert less than the socially optimal care and bikes too much. Moreover, even the car driver takes less than optimal care and also drives too much, even though he is held strictly liable. This is because he does not have to pay for the losses in utility. Furthermore I show that it is possible to obtain the socially optimal levels of care under negligence or comparative negligence. The activity levels on the other hand will never be socially optimal. Hence we see no reason to have a different rule for car-cyclist accident and advocate that it would be more efficient to use a form of negligence rule for all types of accident.

Next, the joint use of **liability, regulation, and a km tax** is analysed. A theoretical model of traffic accidents to analyse the choice of speed and activity of people under these three imperfect instruments or a combination thereof is used. I assume that the accident cost is external to the driver. Hence if there is no means to make the driver pay for these losses, he will not take them into account and he will drive too fast and too much. The aim of the analysis is to see to what extent the expected accident cost can be internalised by various governmental policies. Strict liability does not work perfectly because I assume that it is possible that the driver cannot pay for the damage done, that the probability of prosecution is smaller than one or that people underestimate the probability of being involved in an accident. Regulation - in this case speed limits - and a km tax do not lead to the socially optimal solution because they are uniform measures and only influence either speed or activity directly. No instrument or any combination of instruments leads to the optimal solution. The choice depends on different factors such as the variability of the time, the assets, etc. In general, one should look at the welfare losses under the different instruments and choose that instrument or combination which minimizes the social lost. However, one can say that if there is only one value of time or if there is not a lot of variability in the values of time a combination of regulation and a km tax could be best. On the other hand, if there is a lot of variability and if strict liability used alone is not diluted too much, strict liability could be a better option. I illustrate this numerically for 3 types of roads – urban, interurban, highway, and three types of users – business, commuters and others. I calculate the private and social optimal levels of speed and activity and the levels of speed and activity under the different instruments. I find that the combination of regulation and a km tax is optimal on urban and interurban roads and that strict liability and a km tax together are optimal on highways.

2. SOME REMARKS

The analyses made in this dissertation required some assumptions. This section discusses briefly some of the most important ones, namely the influence of insurance, the influence of accidents on congestion and vice versa and the costs of measures

Firstly, except for chapter four, I assume that there is **no insurance**. In practice, many countries require mandatory car insurance. The liability rules then determine whose insurance has to pay and the question then becomes: how does the insurance company influences the behaviour of their insured? To exclude insurance also implies that potential welfare and behavioural effects from insurance coverage and insurance premiums are ignored. For the sake of clarity, insurance is not explicitly taken into account. Moreover, in the analyses that focus on enforcement, insurance can not play a major role as you cannot insure illegal acts. If on the other hand insurance companies would take into account the criminal record in setting the premiums – as is the case in some states of Canada, but not in European countries – introducing insurance could lead to additional insights. However, if it is included, assumptions on the working of insurance would have to be made and this would not contribute much more than simply leaving it out of the analysis. In chapter five, we could for example have assumed that only the non-insured share of the damage influences the behaviour of the driver and hence the analysis would not have been affected. We could also have assumed that the expected liability equals the expected change in premiums due to an accident. Another option would be a thorough theoretical and empirical analysis of the insurance system. This is, as already said, out of the focus of this dissertation. For a theoretical analysis of the influence of insurances we refer to Shavell (1982), Boyer and Dionne (1987, 1989a) and Dionne ea (1999). Landes (1982), Boyer and Dionne (1989b) and Cohen et al (2003) analyse, among many others, the effects of insurance empirically.

Secondly, I do not consider explicitly **congestion**, although accidents affect congestion and congestion affects the occurrence of accidents. If an accident happens, this may cause a road block and hence congestion. Including this would simply mean adding an additional cost component to the expected accident costs and – except for determining the magnitude of this cost – would not further influence the analyses. Congestion on its turn may also affect the probability and the severity of an accident. As long as the expected accident costs are increasing in the level of speed, this is, low when the road is congested, the analysis made above is not influenced. Given that the levels of speed are low when accidents happen on a congested road, the severity will in general be low. Literature on whether the accident risk is higher at very low speeds than at middle range speed is mixed[105]. Note that on congested roads, speeding fines have no role to play.

Thirdly, for most of the instruments the **implementation costs of the measures** are not explicitly included. Including these costs may alter the choices between increasing and uniform fines, between different liability rules and between different combinations of instruments. Having a system of increasing fines for repeated offenders requires a central database and this comes at a cost. Moreover, if such a database is constructed, it

---

[105] Aarts et al (2006)

might be socially worthwhile to switch to an even more detailed system such as a demerit point system. As already mentioned in chapter four, the choice between different liability rules will certainly be influenced by introducing the implementation costs as the cost of (comparative) negligence is higher than for strict liability. On the other hand, under a rule of (comparative) negligence, the number of cases will be lower. The choice for different combinations of instruments will also depend on the costs of the different measures. For example, the costs of introducing a km tax are still very uncertain and possibly very high.

3. POLICY CONCLUSIONS AND FURTHER RESEARCH

Based on our research, I make the following policy conclusions. I first want to stress that in order to be able to establish a good traffic safety policy, more and better data is needed. For example, data on the actual probability of detection can then give guidance on the optimal fine levels and econometric analysis to determine the influence of lobby groups or the effect of different enforcement policies would become feasible, etc. Secondly, more research is required with respect to influence of combined measures. In real life, measures are never used independently; hence one must take into account their interaction effects. Thirdly, for low probabilities of detection I found that fines should not be higher for repeated offenders. However, for higher probabilities of detection they might. Moreover, I did not consider the possible performance of a demerit point system. A central offender’s database may in any case be worthwhile. Fourthly, we showed that the current strict liability rule for accidents involving a car and a vulnerable road user is probably best replaced with the general negligence rule. Our illustrations showed that if we only take into account traffic safety, it is optimal to lower the speed limit on interurban roads from 90 km/h to 70 km/h and to abolish speed limits on highways, as is the case in Germany. Furthermore, the current fine scheme is socially optimal – this is, equal to the expected accident costs due to speeding – if the current probability of detection equals 0.9% per trip. The question on the magnitude of the present probability of detection remains.. Finally, we want to stress that more research into the social aspects and the social acceptability of measures to improve traffic safety would be very worthwhile. Social acceptability is important because in the end only acceptable measures will be implemented and because they may plead for, for example, income dependent fines.

Bibliography

Aarts, L.T. and I. **Van Schagen** (2006), *Driving speed and the risk of road crashes: a review,* Accident Analysis and Prevention **38**(2), 215-224

Adams, M (1989), New activities and the efficient liability rules, in Faure, Michael; Van den Bergh, Roger (eds), *Essays in law and economics: Corporations, Accident Prevention and Compensation for Losses*, 103-106

Aidt, T.S. (1998), Political Internalization of Economic Externalities and Environmental Policy, *Journal of Public Economics* **69**, 1-16

Anderson, L.R; **Stafford**, S.L. (2003), Punishment in a Regulatory Setting: Experimental Evidence from the VCM, *Journal of Regulatory Economics* **24**(1), 91-110

Arlen, J. (1985), An economic analysis of tort damages for wrongful death, *New York University Law Review* **60**, 1113-1136

Arlen, J. (1990), Re-examining liability rules when injurers as well as victims suffer losses, *International Review of Law and Economics* **10**, 233-239

Arlen, J. (1992), Liability for Physical Injury when Injurers as well as Victims Suffer Losses, *Journal of Law, Economics and Organization* **8**(2), 411-426

Baik, K.H.; **Kim**, I.G. (2001), Optimal Punishment When Individuals May Learn Deviant Values, *International Review of Law and Economics* **21**, 271-284

Bar-Ilan, A. (2000). The response to large and small penalties in a natural experiment. *Working paper*.

Barro, R. (1973), The Control of Politicians: An Economic Model, *Public Choice* **14**, 19-42

Baruya, A. (1997), Speed-Accident Relationships on European Roads, *9th International Conference, Road Safety in Europe*, September 21-23, 1998

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

Belgisch Instituut Voor Verkeersveiligheid (BIVV) (2000), *Jaarverslag Verkeersveiligheid 2000*, www.bivv.be (last checked 11/09/2006), 108 p.

Belgisch Instituut Voor Verkeersveiligheid (BIVV) (2002), *Verkeersveiligheid Statistieken 2001*, www.bivv.be (last checked 11/09/2006), 76 p.

Bentham,J. (1789), *An Introduction to Principles of Moral and Legislation*, Latest edition: Adamant Media Corporation, 2005

Bernheim, B.D., **Whinston**, M. (1986), Menu Auctions, Resource Allocation, and Economic Influence, *Quarterly Journal of Economics* **101,** 1-31

Bose, P. (1995), Regulatory errors, optimal fines and the level of compliance, *Journal of Public Economics* **56**, 475-484.

Boyer, M.; **Dionne**, G. (1987), The Economics of Road Safety, *Transportation Research B* **21B**(5), 413-431

Boyer, M.; **Dionne**, G. (1989a), More on Insurance, Protection and Risk, *Canadian Journal of Economics* **XXII**(1), 202-204

Boyer, M.; **Dionne**, G. (1989b), An Empirical Analysis of Moral Hazard and Experience Rating, *The Review of Economics and Statistics* **LXXI**(1), 128-134

Boyer,M. ; G. **Dionne** and C. **Vanasse**, (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 **67**(3), 279-305

Burnovski, M.; **Safra**, Z. (1994), Deterrence Effect of Sequential Punishment Policies: Should Repeated Offenders Be More Severely Punished? *International Review of Law and Economics* **14**, 341-350

Burrows, P. (1999), Combining Regulation and Legal Liability for the Control of External Costs, *International Review of Law and Economics*, **19**(2), 227-244.

Chu, C.Y.C.; **Hu**, S.-C. and T.-Y. **Huang** (2000), Punishing Repeat Offenders More Severely, *International Review of Law and Economics*, **20**, 127-140.

Cohen, M.A. (2000). Monitoring and Enforcement of Environmental Policy. In: Teitenberg, T. and Folmer, H. (eds.), *International yearbook of environmental and resource economics*, Volume III. Edward Elgar Publishers.

Cohen, A.; **Dehejia**, R. (2003), The Effect of Automobile Insurance and Accident Liability Laws on Traffic Fatalities, *NBER Working Paper 9602*

Cooter, R.; **Ulen**, T. (2004), An economic theory of tort law, in Cooter, R.; Ulen, T. (eds), *Law and Economics*, Addinson-Wesley, Reading, 259-333

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

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

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

Delhaye, E. (2002), Kosten-Baten analyse van het vervangen van een geregeld kruispunt door een rotonde, *Tijdschrift voor economie en management* **XLVII,** 577-605.

Delhaye, E. (2002), Accident Analysis: The Role of Liability Rules – Pecuniary Losses, *mimeo*, 17 p.

Delhaye, E. (2004) Traffic Safety: Speed Limits, Strict Liability and a Km Tax, *ETE-working paper*, http://www.econ.kuleuven.be/ete/publications/default.htm (last checked 11/09/2006)

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

Delhaye, E. (2007/forthcomming), The Enforcement of Speeding: Should Fines Be Higher for Repeated Offenders? *Transportation Planning and Technology* **30** (3)

Dionne, G.; **Laberge-Nadeau**, C. (ed) (1999), Automobile Insurance: Road Safety, New Drivers, Risks, Insurance Fraud and Regulation, Kluwer Academic Publishers, Boston/Dordrecht/London, 351 p.

Dixit, A., **Grossman**, G.M., **Helpman**, E. (1997), Common Agency and Coordination: General Theory and Application to Government Policy Making, *Journal of Political Economy* **104**(4), 752-769

Elvik, R. (1994), The External Costs of Traffic Injury: Definition, Estimation, and Possibilities for Internalization, *Accident Analysis and Prevention*, **26**(6), 719-732

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.

Emons, W. (2003), A Note on the Optimal Punishment for Repeat Offenders, *International Review of Law and Economics* **23**, 253-259

Emons, W. (2004), Subgame Perfect Punishment for Repeat Offenders, *Economic Inquiry* **42** (3), 496-502

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://ec.europa.eu/transport/road/publications/trafficrules/reports/annex_02/topic_tables/annex_2_topic_tables_05_11_speed_limits_en.pdf (last checked 20/03/2007)

European Federation of Road Traffic Victims (2005), Practical and Legal Information for Victims of Road Accidents Abroad and at Home, www.fevr.org (last checked 11/09/2006)

European Road Accident Database (2007), http://ec.europa.eu/transport/roadsafety/road_safety_observatory/care_en.htm (last checked 29/05/07

Eurostat (2007), Energy and Transport in Figures, http://epp.eurostat.ec.europa.eu

Federal Public Service Economy, SMEs, Self employed end Energy (2005), Statistics Belgium, http://statbel.fgov.be (last checked 11/09/2006)

FOD Economie (2006) – Algemene Directie Statistiek, Statistiek van de verkeersongevallen, http://statbel.fgov.be/figures/d364_nl.asp#3 (last checked 11/09/2006)

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

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

Graves, P.E., **Lee**, D.R. and R.L. **Sexton** (1989), Statutes versus enforcement: The case of the optimal speed limit, *The American Economic Review* **79**(4), 932-936

Grossman, G.M., **Helpman,** E. (2001), *Special Interest Politics*, Cambridge, MA, MIT Press.

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

Harford J.D.; **Harrington**, W. (1992), A Reconsideration of Enforcement Leverage when Penalties are Restricted, *Journal of Public Economics* **45**, 391-395

Harrington, W. (1988), Enforcement Leverage when Penalties are Restricted, *Journal of Public Economics* **37**, 29-53

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

International Energy Agency (IEA) (2002), Energy *prices & taxes, quarterly statistics, third quarter*, France

Keller, W.J. (1976) A Nested CES-Type Utility Function and its Demand and Price-Index Functions. *European Economic Review* **7**, 175-186.

Kolstad, C.D; **Ulen**, T.S.; and **Johnson**, G.V. (1990), Ex Post Liability for Harm vs. Ex Ante Safety Regulation: Substitutes or Complements?, *The American Economic Review* **80**(4), 888-901

Landes, E.M. (1982), Insurance, Liability, and Accidents: A Theoretical and Empirical Investigation of the Effect of No-Fault Accidents, *Journal of Law and Economics*, 49-65

Landes, W.M.; **Posner**, R.A (1987), *Catastrophic Personal Injuries, The Economic Structure of Tort Law,* Harvard University Press, 256-272

Landsberger, M.; **Meilijson**, I. (1982), Incentive Generating State Dependent Penalty System. The Case of Income Tax Evasion, *Journal of Public Economics* **19**, 333-352

Lonero, L.P. et al (1995) *Changing road user behaviour: what works in changing road user behaviour.* Safety Research Office of the Safety Policy Branch of the Ontario Government in Canada, 25 p.

Makowsky, M., **Stratmann**, T. (2007), Political economy at any speed: what determines traffic citations? *SSRN working paper.*

Malik, A.S. (1990), Avoidance, Screening and Optimum Enforcement, *RAND Journal of Economics* **21**(3), 341-353

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

Ministerie van Economische Zaken, Bestuur Energie, Afdeling Petroleum (2001), *Dagelijkse prijsberekeningen aardolieproducten,* http://mineco.fgov.be/energy/energy_statistics/Statistics_nl_001.htm (last checked 11/09/2006)

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

Montesquieu, C. (1748). *The spirit of the laws*. Rept. edn, Berkeley, University of California Press. 1977.

N.I.S. (2005), *Het Mobiliteitsportaal – Verkeersongevallen en afgelegde afstanden,* http://statbel.fgov.be/port/mob_nl.asp#A01 (last checked 11/09/2006)

Nyborg, K.; **Telle**, K. (2004), The role of warnings in regulation: Keeping control with less punishment, *Journal of Public Economics* **88** (12), 2801-2816

OECD (2002) Safety on Roads, What's the Vision?, OECD, Paris, 123 p.

Peirson, J.; **Skinner**, I.; **Vickerman**, R. (1998) The Microeconomic Analysis of the External Costs of Road Accidents. *Economica* **65**, 429-440.

Persson and **Tabellini** (2000), *Political Economics: Explaining economic policy*, the MIT Press, 533 p.

Persson, T. (1998), Economic Policy and Special Interest Politics, *The Economic Journal* **108** (March), 310-327 www.petrolfed.be (2006) (last checked 11/09/2006)

Polinsky, A.M., **Shavell**, S. (1979), The Optimal Tradeoff between Probability and Magnitude of Fines *The American Economic Review* **69**(5), 880-891

Polinsky, A.M., **Shavell**, S. (1998), On Offense History and the Theory of Deterrence, *International Review of Law and* Economics 18, 305-324

Polinsky, A.M.; **Shavell**, S. (2000) The Economic Theory of Public Enforcement of Law. *Journal of Economic Literature* **38**, 45-76.

Polinsky, A.M. and D.L. **Rubinfeld** (1991), A model of optimal fines for repeat offenders, *Journal of Public Economics* **46**, 291-306

Posner, R.A. (1998), *Economic Analysis of Law*, 5th edition, Aspen Law and Business, New York

Proost, S. en **Van Dender**, K. (1999) *Final Report For Publication: TRENEN II STRAN*. Project funded by the European Commission under the transport RTD programme of the 4th framework programme. pp. 1-108.

Rietveld, P.; A. **van Binsbergen**, T. **Schoemaker** and P. **Peeters** (1998a)**,** *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, 206-225

Rietveld, P., **Shefer**, D. (1998b) Speed Choice, Speed Variance, and Speed Limits, A second-best Instrument to Correct for Road Transport Externalities. *Journal of Transport Economics and Policy* **32** (2), 187-202.

Rothengatter, J.A. (1991) Normative behaviour is unattractive if it is abnormal : Relationships between norms, attitudes and traffic law. In M. Koonstra & J. Christensen (Eds.), *Enforcement and Rewarding: Strategies and Effects.* Leidschendam. Institute of Road Safety Research.

Rothschild, M. **;** **Stiglitz**, J.E. (1970) Increasing Risk : I. A Definition, *Journal of Economic Theory* **2**(3), 225-243

Rothschild, M. **;** **Stiglitz**, J.E. (1971) Increasing Risk : II. Its Economic Consequences, *Journal of Economic Theory* **3**(1), 66-84

Rubinstein, A. (1979), An optimal conviction policy for offenses that may have been committed by accident. In S.Brams, A. Schotter,&G. Schwödiauer (Eds.), *Applied game theory* (pp. 406–413). Würzburg: Physica-Verlag.

Russell, C.S. (1990), Game models for structuring monitoring and enforcement systems, *Natural Resource Modeling* **4**, 143-173

SARTRE 3 (2004) *European Drivers and Road Risk*, Part 1, Report on Principle Analyses, 290 p. http://sartre.inrets.fr (last checked 23/03/2007)

Schmitz, P. W. (2000), On the Joint Use of Liability and Safety Regulation, *International Review of Law and Economics* **20**, 371-382.

Schoups, L., **Van Bosstraeten**, W. (2000), *Verkeerszakboekje*, Kluwer, 304 p.

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.

Shavell, S. (1982), On liability and insurance, *The Bell Journal of Economics* **13**, 120-132

Shavell, S. (1984a) A model of the optimal use of liability and safety regulation. *Rand Journal of Economics* **15**(2), 271-280.

Shavell, S. (1984b), Liability for Harm versus Regulation of Safety, *Journal of Legal Studies* **13**(2), 357-374.

Shavell, S. (1987), *Economic Analysis of Accident Law* , Harvard University Press, 312 p.

Shavell, S. (2004), *Foundations of Economic Analysis of Law*, Harvard University Press, Cambridge, 737 p.

Sloan, F.A.; **Reilly**, B.A.; **Schenzler**, C.M. (1994), Tort Liability versus Other Approaches for Deterring Careless Driving, *International Review of Law and Economics* **14**, 53-71

Stigler, G.J. (1970), The Optimum Enforcement of Laws, *Journal of Political Economy* **78**, 526-536

Stradling, S.; M. **Meadows** and S. **Beatty** (2000), *Characteristics of Speeding, Violating and Thrill-seeking Drivers*, International Conference on Traffic and Transport Psychology, Bern, September 2000

Svenson, O. (1981), Are We All Less Risky and More Skillful than Our Fellow Drivers? *Acta Psychologica* **47**, 143-148

Toint (2001) *Enquete nationale sur la mobilité des menages: Réalisation et résultats*, Rapport Final, Contrat MD/13/036 Programme "mobilité durable" Services fédéraux des Affaires Scientifiques, Techniques et Culturelles, Plan d'appui scientifique à une politique de développement durable

UNITE, (2001) *Valuation Conventions for Unite*. (Downloadable from website: http://www.its.leeds.ac.uk/projects/unite/D5_Annex3.pdf)

Van Dam, M. (2001), Verkeersongevallen. Een rechtseconomische, empirische en positiefrechtelijk onderzoek naar de werking van de aansprakelijkheid, verzekering en veiligheidsregulering in het verkeer, Boom Juridische Uitgevers, 675 p.

Van den Bergh, R. (1998), Automatische vergoeding van schade geleden door zwakke verkeersdeelnemers: een rechtseconomische kritiek, in Faure, M.; Hartlief (eds.), *Verkeersaansprakelijkheid in België en Nederland*, Inersentia Uitgevers, Antwerpen-Groningen

van den Hauten, M. **Rademakers**, J. (2005), Nederlandse verkeersboetes in internationaal perspectief – verkennend onderzoek in twaalf Europese landen, WODC Ministerie van Justitie, Den Haag

Vanlaar,W. (2000) Resultaten proefproject "gedragsmeting snelheid" in Vlaams Brabant: Niet-naleven van snelheidslimieten schering en inslag, *Via Secura* **52**, 16-17

Verhoef, E.T.; **Rouwendal**, J. (2004), A behavioural model of traffic congestion. Endogenizing speed choice, traffic safety and time losses, *Journal of Urban Economics* **56**, 408-434

Viscusi, W.K.; **Evans**, W.N. (1990), Utility functions that depend on health status: estimates and economic implications, *American Economic Review* **80**(3), 353-371

Visscher, L. T. (1998), The Problem of Uncompensated Losses. The Case of Dutch Traffic Liability, in Ott, C.; Van Wangenheim, G. (eds.), *Essays in Law and Economics*

IV; Public Law, Private Law, and Adjudication, Maklu, Antwerpen-Apeldoorn, 203-221

Visscher, L.T.; **Van Den Bergh**, R.J. (1998), Over fietsende juristen en autorijdende rechtseconomen of een nieuwe fase in het debat over verkeersveiligheid, *Nederlands Juristen Blad* **73**, 122-127

Winston, W.L. (1994), Operations Research: Applications and Algorithms, third edition, Duxbury Press, California

www.wegcode.be (last checked 11/09/2006)

Doctoral dissertations from the Faculty of Economics and Applied Economics

(from August 1, 1971)

1. GEPTS, Stefaan
   Stability and efficiency of resource allocation processes in discrete commodity spaces.
   Leuven, KUL, 1971. 86 pp.

2. PEETERS, Theo
   Determinanten van de internationale handel in fabrikaten.
   Leuven, Acco, 1971. 290 pp.

3. VAN LOOY, Wim
   Personeelsopleiding: een onderzoek naar investeringsaspekten van opleiding.
   Hasselt, Vereniging voor wetenschappelijk onderzoek in Limburg, 1971. VII, 238 pp.

4. THARAKAN, Mathew
   Indian exports to the European community: problems and prospects.
   Leuven, Faculty of economics and applied economics, 1972. X,343 pp.

5. HERROELEN, Willy
   Heuristische programmatie: methodologische benadering en praktische toepassing op complexe combinatorische problemen.
   Leuven, Aurelia scientifica, 1972. X, 367 pp.

6. VANDENBULCKE, Jacques
   De studie en de evaluatie van data-organisatiemethodes en data-zoekmethodes.
   Leuven, s.n., 1973. 3 V.

7. PENNYCUICK, Roy A.
   The economics of the ecological syndrome.
   Leuven, Acco, 1973. XII, 177 pp.

8. KAWATA, T. Bualum
   Formation du capital d'origine belge, dette publique et stratégie du développement au Zaire.
   Leuven, KUL, 1973. V, 342 pp.

9. DONCKELS, Rik
   Doelmatige oriëntering van de sectorale subsidiepolitiek in België: een theoretisch onderzoek met empirische toetsing.
   Leuven, K.U.Leuven, 1974. VII, 156 pp.

10. VERHELST, Maurice
    Contribution to the analysis of organizational information systems and their financial benefits.
    Leuven, K.U.Leuven, 1974. 2 V.

11. CLEMEUR, Hugo
    Enkele verzekeringstechnische vraagstukken in het licht van de nutstheorie.
    Leuven, Aurelia scientifica, 1974. 193 pp.

12. HEYVAERT, Edward
    De ontwikkeling van de moderne bank- en krediettechniek tijdens de zestiende en zeventiende eeuw in Europa en te Amsterdam in het bijzonder.
    Leuven, K.U.Leuven, 1975. 186 pp.

13. VERTONGHEN, Robert
    Investeringscriteria voor publieke investeringen: het uitwerken van een operationele theorie met een toepassing op de verkeersinfrastructuur.
    Leuven, Acco, 1975. 254 pp.

14. Niet toegekend.

15. VANOVERBEKE, Lieven
    Microeconomisch onderzoek van de sectoriële arbeidsmobiliteit.
    Leuven, Acco, 1975. 205 pp.

16. DAEMS, Herman
    The holding company: essays on financial intermediation, concentration and capital market imperfections in the Belgian economy.
    Leuven, K.U.Leuven, 1975. XII, 268 pp.

17. VAN ROMPUY, Eric
    Groot-Brittannië en de Europese monetaire integratie: een onderzoek naar de gevolgen van de Britse toetreding op de geplande Europese monetaire unie.
    Leuven, Acco, 1975. XIII, 222 pp.

18. MOESEN, Wim
    Het beheer van de staatsschuld en de termijnstructuur van de intrestvoeten met een toepassing voor België.
    Leuven, Vander, 1975. XVI, 250 pp.

19. LAMBRECHT, Marc
    Capacity constrained multi-facility dynamic lot-size problem.
    Leuven, KUL, 1976. 165 pp.

20. RAYMAECKERS, Erik
    De mens in de onderneming en de theorie van het producenten-gedrag: een bijdrage tot transdisciplinaire analyse.
    Leuven, Acco, 1976. XIII, 538 pp.

21. TEJANO, Albert
    Econometric and input-output models in development planning: the case of the Philippines.
    Leuven, KUL, 1976. XX, 297 pp.

22. MARTENS, Bernard
    Prijsbeleid en inflatie met een toepassing op België.
    Leuven, KUL, 1977. IV, 253 pp.

23. VERHEIRSTRAETEN, Albert
    Geld, krediet en intrest in de Belgische financiële sector.
    Leuven, Acco, 1977. XXII, 377 pp.

24. GHEYSSENS, Lieven
International diversification through the government bond market: a risk-return analysis.
Leuven, s.n., 1977. 188 pp.

25. LEFEBVRE, Chris
Boekhoudkundige verwerking en financiële verslaggeving van huurkooptransacties en verkopen op afbetaling bij ondernemingen die aan consumenten verkopen.
Leuven, KUL, 1977. 228 pp.

26. KESENNE, Stefan
Tijdsallocatie en vrijetijdsbesteding: een econometrisch onderzoek.
Leuven, s.n., 1978. 163 pp.

27. VAN HERCK, Gustaaf
Aspecten van optimaal bedrijfsbeleid volgens het marktwaardecriterium: een risico-rendementsanalyse.
Leuven, KUL, 1978. IV, 163 pp.

28. VAN POECK, Andre
World price trends and price and wage development in Belgium: an investigation into the relevance of the Scandinavian model of inflation for Belgium.
Leuven, s.n., 1979. XIV, 260 pp.

29. VOS, Herman
De industriële technologieverwerving in Brazilië: een analyse.
Leuven, s.n., 1978. onregelmatig gepagineerd.

30. DOMBRECHT, Michel
Financial markets, employment and prices in open economies.
Leuven, KUL, 1979. 182 pp.

31. DE PRIL, Nelson
Bijdrage tot de actuariële studie van het bonus-malussysteem.
Brussel, OAB, 1979. 112 pp.

32. CARRIN, Guy
Economic aspects of social security: a public economics approach.
Leuven, KUL, 1979. onregelmatig gepagineerd

33. REGIDOR, Baldomero
An empirical investigation of the distribution of stock-market prices and weak-form efficiency of the Brussels stock exchange.
Leuven, KUL, 1979. 214 pp.

34. DE GROOT, Roger
Ongelijkheden voor stop loss premies gebaseerd op E.T. systemen in het kader van de veralgemeende convexe analyse.
Leuven, KUL, 1979. 155 pp.

35. CEYSSENS, Martin
On the peak load problem in the presence of rationizing by waiting.
Leuven, KUL, 1979. IX, 217 pp.

36. ABDUL RAZK ABDUL
Mixed enterprise in Malaysia: the case study of joint venture between Malysian public corporations and foreign enterprises.
Leuven, KUL, 1979. 324 pp.

37. DE BRUYNE, Guido
Coordination of economic policy: a game-theoretic approach.
Leuven, KUL, 1980. 106 pp.

38. KELLES, Gerard
Demand, supply, price change and trading volume on financial markets of the matching-order type. = Vraag, aanbod, koersontwikkeling en omzet op financiële markten van het Europese type.
Leuven, KUL, 1980. 222 pp.

39. VAN EECKHOUDT, Marc
De invloed van de looptijd, de coupon en de verwachte inflatie op het opbrengstverloop van vastrentende financiële activa.
Leuven, KUL, 1980. 294 pp.

40. SERCU, Piet
Mean-variance asset pricing with deviations from purchasing power parity.
Leuven, s.n., 1981. XIV, 273 pp.

41. DEQUAE, Marie-Gemma
Inflatie, belastingsysteem en waarde van de onderneming.
Leuven, KUL, 1981. 436 pp.

42. BRENNAN, John
An empirical investigation of Belgian price regulation by prior notification: 1975 - 1979 - 1982.
Leuven, KUL, 1982. XIII, 386 pp.

43. COLLA, Annie
Een econometrische analyse van ziekenhuiszorgen.
Leuven, KUL, 1982. 319 pp.

44. Niet toegekend.

45. SCHOKKAERT, Eric
Modelling consumer preference formation.
Leuven, KUL, 1982. VIII, 287 pp.

46. DEGADT, Jan
Specificatie van een econometrisch model voor vervuilingsproblemen met proeven van toepassing op de waterverontreiniging in België.
Leuven, s.n., 1982. 2 V.

47. LANJONG, Mohammad Nasir
A study of market efficiency and risk-return relationships in the Malaysian capital market.
s.l., s.n., 1983. XVI, 287 pp.

48. PROOST, Stef
De allocatie van lokale publieke goederen in een economie met een centrale overheid en lokale overheden.
Leuven, s.n., 1983. onregelmatig gepagineerd.

49. VAN HULLE, Cynthia (/08/83)
Shareholders' unanimity and optimal corporate decision making in imperfect capital markets.
s.l., s.n., 1983. 147 pp. + appendix.

50. VAN WOUWE, Martine (2/12/83)
Ordening van risico's met toepassing op de berekening van ultieme ruïnekansen.
Leuven, s.n., 1983. 109 pp.

51. D'ALCANTARA, Gonzague (15/12/83)
SERENA: a macroeconomic sectoral regional and national account econometric model for the Belgian economy.
Leuven, KUL, 1983. 595 pp.

52. D'HAVE, Piet (24/02/84)
De vraag naar geld in België.
Leuven, KUL, 1984. XI, 318 pp.

53. MAES, Ivo (16/03/84)
The contribution of J.R. Hicks to macro-economic and monetary theory.
Leuven, KUL, 1984. V, 224 pp.

54. SUBIANTO, Bambang (13/09/84)
A study of the effects of specific taxes and subsidies on a firms' R&D investment plan.
s.l., s.n., 1984. V, 284 pp.

55. SLEUWAEGEN, Leo (26/10/84)
Location and investment decisions by multinational enterprises in Belgium and Europe.
Leuven, KUL, 1984. XII, 247 pp.

56. GEYSKENS, Erik (27/03/85)
Produktietheorie en dualiteit.
Leuven, s.n., 1985. VII, 392 pp.

57. COLE, Frank (26/06/85)
Some algorithms for geometric programming.
Leuven, KUL, 1985. 166 pp.

58. STANDAERT, Stan (26/09/86)
A study in the economics of repressed consumption.
Leuven, KUL, 1986. X, 380 pp.

59. DELBEKE, Jos (03/11/86)
Trendperioden in de geldhoeveelheid van België 1877-1983: een theoretische en empirische analyse van de "Banking school" hypothese.
Leuven, KUL, 1986. XII, 430 pp.

60. VANTHIENEN, Jan (08/12/86)
Automatiseringsaspecten van de specificatie, constructie en manipulatie van beslissingstabellen.
Leuven, s.n., 1986. XIV, 378 pp.

61. LUYTEN, Robert (30/04/87)
A systems-based approach for multi-echelon production/inventory systems.
s.l., s.n., 1987. 3V.

62. MERCKEN, Roger (27/04/87)
De invloed van de data base benadering op de interne controle.
Leuven, s.n., 1987. XIII, 346 pp.

63. VAN CAYSEELE, Patrick (20/05/87)
Regulation and international innovative activities in the pharmaceutical industry.
s.l., s.n., 1987. XI, 169 pp.

64. FRANCOIS, Pierre (21/09/87)
De empirische relevantie van de independence from irrelevant alternatives. Assumptie indiscrete keuzemodellen.
Leuven, s.n., 1987. IX, 379 pp.

65. DECOSTER, André (23/09/88)
Family size, welfare and public policy.
Leuven, KUL. Faculteit Economische en Toegepaste Economische Wetenschappen, 1988. XIII, 444 pp.

66. HEIJNEN, Bart (09/09/88)
Risicowijziging onder invloed van vrijstellingen en herverzekeringen: een theoretische analyse van optimaliteit en premiebepaling.
Leuven, KUL. Faculteit Economische en Toegepaste Economische Wetenschappen, 1988. onregelmatig gepagineerd.

67. GEEROMS, Hans (14/10/88)
Belastingvermijding. Theoretische analyse van de determinanten van de belastingontduiking en de belastingontwijking met empirische verificaties.
Leuven, s.n., 1988. XIII, 409, 5 pp.

68. PUT, Ferdi (19/12/88)
Introducing dynamic and temporal aspects in a conceptual (database) schema.
Leuven, KUL. Faculteit Economische en Toegepaste Economische Wetenschappen, 1988. XVIII, 415 pp.

69. VAN ROMPUY, Guido (13/01/89)
A supply-side approach to tax reform programs. Theory and empirical evidence for Belgium.
Leuven, KUL. Faculteit Economische en Toegepaste Economische Wetenschappen, 1989. XVI, 189, 6 pp.

70. PEETERS, Ludo (19/06/89)
Een ruimtelijk evenwichtsmodel van de graanmarkten in de E.G.: empirische specificatie en beleidstoepassingen.
Leuven, K.U.Leuven. Faculteit Economische en Toegepaste Economische Wetenschappen, 1989. XVI, 412 pp.

71. PACOLET, Jozef (10/11/89)
Marktstructuur en operationele efficiëntie in de Belgische financiële sector.
Leuven, K.U.Leuven. Faculteit Economische en Toegepaste Economische Wetenschappen, 1989. XXII, 547 pp.

72. VANDEBROEK, Martina (13/12/89)
Optimalisatie van verzekeringscontracten en premieberekeningsprincipes.
Leuven, K.U.Leuven. Faculteit Economische en Toegepaste Economische Wetenschappen, 1989. 95 pp.

73. WILLEKENS, Francois ()
Determinance of government growth in industrialized countries with applications to Belgium.
Leuven, K.U.Leuven. Faculteit Economische en Toegepaste Economische Wetenschappen, 1990. VI, 332 pp.

74. VEUGELERS, Reinhilde (02/04/90)
Scope decisions of multinational enterprises.
Leuven, K.U.Leuven. Faculteit Economische en Toegepaste Economische Wetenschappen, 1990. V, 221 pp.

75. KESTELOOT, Katrien (18/06/90)
Essays on performance diagnosis and tacit cooperation in international oligopolies.
Leuven, K.U.Leuven. Faculteit Economische en Toegepaste Economische Wetenschappen, 1990. 227 pp.

76. WU, Changqi (23/10/90)
Strategic aspects of oligopolistic vertical integration.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1990. VIII, 222 pp.

77. ZHANG, Zhaoyong (08/07/91)
A disequilibrium model of China's foreign trade behaviour.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1991. XII, 256 pp.

78. DHAENE, Jan (25/11/91)
Verdelingsfuncties, benaderingen en foutengrenzen van stochastische grootheden geassocieerd aan verzekeringspolissen en -portefeuilles.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1991. 146 pp.

79. BAUWELINCKX, Thierry (07/01/92)
Hierarchical credibility techniques.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1992. 130 pp.

80. DEMEULEMEESTER, Erik (23/3/92)
Optimal algorithms for various classes of multiple resource-constrained project scheduling problems.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1992. 180 pp.

81. STEENACKERS, Anna (1/10/92)
    Risk analysis with the classical actuarial risk model: theoretical extensions and applications to Reinsurance.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1992. 139 pp.

82. COCKX, Bart (24/09/92)
    The minimum income guarantee. Some views from a dynamic perspective.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1992. XVII, 401 pp.

83. MEYERMANS, Eric (06/11/92)
    Econometric allocation systems for the foreign exchange market: Specification, estimation and testing of transmission mechanisms under currency substitution.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1992. XVIII, 343 pp.

84. CHEN, Guoqing (04/12/92)
    Design of fuzzy relational databases based on fuzzy functional dependency.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1992. 176 pp.

85. CLAEYS, Christel (18/02/93)
    Vertical and horizontal category structures in consumer decision making: The nature of product hierarchies and the effect of brand typicality.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1993. 348 pp.

86. CHEN, Shaoxiang (25/03/93)
    The optimal monitoring policies for some stochastic and dynamic production processes.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1993. 170 pp.

87. OVERWEG, Dirk (23/04/93)
    Approximate parametric analysis and study of cost capacity management of computer configurations.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1993. 270 pp.

88. DEWACHTER, Hans (22/06/93)
    Nonlinearities in speculative prices: The existence and persistence of nonlinearity in foreign exchange rates.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1993. 151 pp.

89. LIN, Liangqi (05/07/93)
    Economic determinants of voluntary accounting choices for R & D expenditures in Belgium.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1993. 192 pp.

90. DHAENE, Geert (09/07/93)
    Encompassing: formulation, properties and testing.
    Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1993. 117 pp.

91. LAGAE, Wim (20/09/93)
Marktconforme verlichting van soevereine buitenlandse schuld door private crediteuren: een neo-institutionele analyse.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1993. 241 pp.

92. VAN DE GAER, Dirk (27/09/93)
Equality of opportunity and investment in human capital.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1993. 172 pp.

93. SCHROYEN, Alfred (28/02/94)
Essays on redistributive taxation when monitoring is costly.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1994. 203 pp. + V.

94. STEURS, Geert (15/07/94)
Spillovers and cooperation in research and development.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1994. 266 pp.

95. BARAS, Johan (15/09/94)
The small sample distribution of the Wald, Lagrange multiplier and likelihood ratio tests for homogeneity and symmetry in demand analysis: a Monte Carlo study.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1994. 169 pp.

96. GAEREMYNCK, Ann (08/09/94)
The use of depreciation in accounting as a signalling device.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1994. 232 pp.

97. BETTENDORF, Leon (22/09/94)
A dynamic applied general equilibrium model for a small open economy.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1994. 149 pp.

98. TEUNEN, Marleen (10/11/94)
Evaluation of interest randomness in actuarial quantities.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1994. 214 pp.

99. VAN OOTEGEM, Luc (17/01/95)
An economic theory of private donations.
Leuven. K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 236 pp.

100. DE SCHEPPER, Ann (20/03/95)
Stochastic interest rates and the probabilistic behaviour of actuarial functions.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 211 pp.

101. LAUWERS, Luc (13/06/95)
Social choice with infinite populations.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 79 pp.

102. WU, Guang (27/06/95)
A systematic approach to object-oriented business modeling.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 248 pp.

103. WU, Xueping (21/08/95)
Term structures in the Belgian market: model estimation and pricing error analysis.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 133 pp.

104. PEPERMANS, Guido (30/08/95)
Four essays on retirement from the labor force.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 128 pp.

105. ALGOED, Koen (11/09/95)
Essays on insurance: a view from a dynamic perspective.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 136 pp.

106. DEGRYSE, Hans (10/10/95)
Essays on financial intermediation, product differentiation, and market structure.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 218 pp.

107. MEIR, Jos (05/12/95)
Het strategisch groepsconcept toegepast op de Belgische financiële sector.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1995. 257 pp.

108. WIJAYA, Miryam Lilian (08/01/96)
Voluntary reciprocity as an informal social insurance mechanism: a game theoretic approach.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1996. 124 pp.

109. VANDAELE, Nico (12/02/96)
The impact of lot sizing on queueing delays: multi product, multi machine models.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1996. 243 pp.

110. GIELENS, Geert (27/02/96)
Some essays on discrete time target zones and their tails.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1996. 131 pp.

111. GUILLAUME, Dominique (20/03/96)
Chaos, randomness and order in the foreign exchange markets. Essays on the modelling of the markets.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1996. 171 pp.

112. DEWIT, Gerda (03/06/96)
Essays on export insurance subsidization.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1996. 186 pp.

113. VAN DEN ACKER, Carine (08/07/96)
Belief-function theory and its application to the modeling of uncertainty in financial statement auditing.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1996. 147 pp.

114. IMAM, Mahmood Osman (31/07/96)
Choice of IPO Flotation Methods in Belgium in an Asymmetric Information Framework and Pricing of IPO's in the Long-Run.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1996. 221 pp.

115. NICAISE, Ides (06/09/96)
Poverty and Human Capital.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1996. 209 pp.

116. EYCKMANS, Johan (18/09/97)
On the Incentives of Nations to Join International Environmental Agreements.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1997. XV + 348 pp.

117. CRISOLOGO-MENDOZA, Lorelei (16/10/97)
Essays on Decision Making in Rural Households: a study of three villages in the Cordillera Region of the Philippines.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1997. 256 pp.

118. DE REYCK, Bert (26/01/98)
Scheduling Projects with Generalized Precedence Relations: Exact and Heuristic Procedures.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1998. XXIV + 337 pp.

119. VANDEMAELE Sigrid (30/04/98)
Determinants of Issue Procedure Choice within the Context of the French IPO Market: Analysis within an Asymmetric Information Framework.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1998. 241 pp.

120. VERGAUWEN Filip (30/04/98)
Firm Efficiency and Compensation Schemes for the Management of Innovative Activities and Knowledge Transfers.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1998. VIII + 175 pp.

121. LEEMANS Herlinde (29/05/98)
The Two-Class Two-Server Queueing Model with Nonpreemptive Heterogeneous Priority Structures.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1998. 211 pp.

122. GEYSKENS Inge (4/09/98)
Trust, Satisfaction, and Equity in Marketing Channel Relationships.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1998. 202 pp.

123. SWEENEY John (19/10/98)
Why Hold a Job ? The Labour Market Choice of the Low-Skilled.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1998. 278 pp.

124. GOEDHUYS Micheline (17/03/99)
Industrial Organisation in Developing Countries, Evidence from Côte d'Ivoire.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. 251 pp.

125. POELS Geert (16/04/99)
On the Formal Aspects of the Measurement of Object-Oriented Software Specifications.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. 507 pp.

126. MAYERES Inge (25/05/99)
The Control of Transport Externalities: A General Equilibrium Analysis.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. XIV + 294 pp.

127. LEMAHIEU Wilfried (5/07/99)
Improved Navigation and Maintenance through an Object-Oriented Approach to Hypermedia Modelling.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. 284 pp.

128. VAN PUYENBROECK Tom (8/07/99)
Informational Aspects of Fiscal Federalism.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. 192 pp.

129. VAN DEN POEL Dirk (5/08/99)
Response Modeling for Database Marketing Using Binary Classification.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. 342 pp.

130. GIELENS Katrijn (27/08/99)
International Entry Decisions in the Retailing Industry: Antecedents and Performance Consequences.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. 336 pp.

131. PEETERS Anneleen (16/12/99)
Labour Turnover Costs, Employment and Temporary Work.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. 207 pp.

132. VANHOENACKER Jurgen (17/12/99)
Formalizing a Knowledge Management Architecture Meta-Model for Integrated Business Process Management.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 1999. 252 pp.

133. NUNES Paulo (20/03/2000)
Contingent Valuation of the Benefits of Natural Areas and its Warmglow Component.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2000. XXI + 282 pp.

134. VAN DEN CRUYCE Bart (7/04/2000)
Statistische discriminatie van allochtonen op jobmarkten met rigide lonen.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2000. XXIII + 441 pp.

135. REPKINE Alexandre (15/03/2000)
Industrial restructuring in countries of Central and Eastern Europe: Combining branch-, firm- and product-level data for a better understanding of Enterprises' behaviour during transition towards market economy.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2000. VI + 147 pp.

136. AKSOY, Yunus (21/06/2000)
Essays on international price rigidities and exchange rates.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2000. IX + 236 pp.

137. RIYANTO, Yohanes Eko (22/06/2000)
Essays on the internal and external delegation of authority in firms.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2000. VIII + 280 pp.

138. HUYGHEBAERT, Nancy (20/12/2000)
The Capital Structure of Business Start-ups.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2000. VIII + 332 pp.

139. FRANCKX Laurent (22/01/2001)
Ambient Inspections and Commitment in Environmental Enforcement.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001 VIII + 286 pp.

140. VANDILLE Guy (16/02/2001)
Essays on the Impact of Income Redistribution on Trade.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001 VIII + 176 pp.

141. MARQUERING Wessel (27/04/2001)
Modeling and Forecasting Stock Market Returns and Volatility.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. V + 267 pp.

142. FAGGIO Giulia (07/05/2001)
Labor Market Adjustment and Enterprise Behavior in Transition.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. 150 pp.

143. GOOS Peter (30/05/2001)
The Optimal Design of Blocked and Split-plot experiments.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001.X + 224 pp.

144. LABRO Eva (01/06/2001)
Total Cost of Ownership Supplier Selection based on Activity Based Costing and Mathematical Programming.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. 217 pp.

145. VANHOUCKE Mario (07/06/2001)
Exact Algorithms for various Types of Project Scheduling Problems. Nonregular Objectives and time/cost Trade-offs. 316
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. 316 pp.

146. BILSEN Valentijn (28/08/2001)
Entrepreneurship and Private Sector Development in Central European Transition Countries.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. XVI + 188 pp.

147. NIJS Vincent (10/08/2001)
Essays on the dynamic Category-level Impact of Price promotions.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001.

148. CHERCHYE Laurens (24/09/2001)
Topics in Non-parametric Production and Efficiency Analysis.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. VII + 169 pp.

149. VAN DENDER Kurt (15/10/2001)
Aspects of Congestion Pricing for Urban Transport.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. VII + 203 pp.

150. CAPEAU Bart (26/10/2001)
In defence of the excess demand approach to poor peasants' economic behaviour. Theory and Empirics of non-recursive agricultural household modelling.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. XIII + 286 blz.

151. CALTHROP Edward (09/11/2001)
Essays in urban transport economics.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001.

152. VANDER BAUWHEDE Heidi (03/12/2001)
Earnings management in an Non-Anglo-Saxon environment.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2001. 408 pp.

153. DE BACKER Koenraad (22/01/2002)
Multinational firms and industry dynamics in host countries : the case of Belgium.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. VII + 165 pp.

154. BOUWEN Jan (08/02/2002)
Transactive memory in operational workgroups. Concept elaboration and case study.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. 319 pp. + appendix 102 pp.

155. VAN DEN BRANDE Inge (13/03/2002)
The psychological contract between employer and employee : a survey among Flemish employees.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. VIII + 470 pp.

156. VEESTRAETEN Dirk (19/04/2002)
Asset Price Dynamics under Announced Policy Switching.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. 176 pp.

157. PEETERS Marc (16/05/2002)
One Dimensional Cutting and Packing : New Problems and Algorithms.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002.

158. SKUDELNY Frauke (21/05/2002)
Essays on The Economic Consequences of the European Monetary Union.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002.

159. DE WEERDT Joachim (07/06/2002)
Social Networks, Transfers and Insurance in Developing countries.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. VI + 129 pp.

160. TACK Lieven (25/06/2002)
Optimal Run Orders in Design of Experiments.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. XXXI + 344 pp.

161. POELMANS Stephan (10/07/2002)
Making Workflow Systems work. An investigation into the Importance of Task-appropriation fit, End-user Support and other Technological Characteristics. Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. 237 pp.

162. JANS Raf (26/09/2002)
Capacitated Lot Sizing Problems : New Applications, Formulations and Algorithms.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002.

163. VIAENE Stijn (25/10/2002)
Learning to Detect Fraud from enriched Insurance Claims Data (Context, Theory and Applications).
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. 315 pp.

164. AYALEW Tekabe (08/11/2002)
Inequality and Capital Investment in a Subsistence Economy.Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. V + 148 pp.

165. MUES Christophe (12/11/2002)
On the Use of Decision Tables and Diagrams in Knowledge Modeling and Verification.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. 222 pp.

166. BROCK Ellen (13/03/2003)
The Impact of International Trade on European Labour Markets.
K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002.

167. VERMEULEN Frederic (29/11/2002)
Essays on the collective Approach to Household Labour Supply.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. XIV + 203 pp.

168. CLUDTS Stephan (11/12/2002)
Combining participation in decision-making with financial participation : theoretical and empirical perspectives.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2002. XIV + 247 pp.

169. WARZYNSKI Frederic (09/01/2003)
The dynamic effect of competition on price cost margins and innovation.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen
2003.

170. VERWIMP Philip (14/01/2003)
Development and genocide in Rwanda ; a political economy analysis of peasants and power under the Habyarimana regime.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

171. BIGANO Andrea (25/02/2003)
Environmental regulation of the electricity sector in a European Market Framework.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003. XX + 310 pp.

172. MAES Konstantijn (24/03/2003)
Modeling the Term Structure of Interest Rates Across Countries.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003. V+246 pp.

173. VINAIMONT Tom (26/02/2003)
The performance of One- versus Two-Factor Models of the Term Structure of Interest Rates.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

174. OOGHE Erwin (15/04/2003)
Essays in multi-dimensional social choice.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003. VIII+108 pp.

175. FORRIER Anneleen (25/04/2003)
Temporary employment, employability and training.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

176. CARDINAELS Eddy (28/04/2003)
The role of cost system accuracy in managerial decision making.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003. 144 pp.

177. DE GOEIJ Peter (02/07/2003)
Modeling Time-Varying Volatility and Interest Rates.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003. VII+225 pp.

178. LEUS Roel (19/09/2003)
The generation of stable project plans. Complexity and exact algorithms.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

179. MARINHEIRO Carlos (23/09/2003)
EMU and fiscal stabilisation policy : the case of small countries.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen
2003.

180. BAESENS Bart (24/09/2003)
Developing intelligent systems for credit scoring using machine learning techniques.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

181. KOCZY Laszlo (18/09/2003)
Solution concepts and outsider behaviour in coalition formation games.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

182. ALTOMONTE Carlo (25/09/2003)
Essays on Foreign Direct Investment in transition countries : learning from the evidence.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

183. DRIES Liesbeth (10/11/2003)
Transition, Globalisation and Sectoral Restructuring: Theory and Evidence from the Polish Agri-Food Sector. Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

184. DEVOOGHT Kurt (18/11/2003)
Essays On Responsibility-Sensitive Egalitarianism and the Measurement of Income Inequality. Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

185. DELEERSNYDER Barbara (28/11/2003)
Marketing in Turbulent Times. Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

186. ALI Daniel (19/12/2003)
Essays on Household Consumption and Production Decisions under Uncertainty in Rural Ethiopia.”. Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2003.

187. WILLEMS Bert (14/01/2004)
Electricity networks and generation market power.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

188. JANSSENS Gust (30/01/2004)
Advanced Modelling of Conditional Volatility and Correlation in Financial Markets.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

189. THOEN Vincent (19/01/2004)
"On the valuation and disclosure practices implemented by venture capital providers"
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

190. MARTENS Jurgen (16/02/2004)
“A fuzzy set and stochastic system theoretic technique to validate simulation models”.Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

191. ALTAVILLA Carlo (21/05/2004)
“Monetary policy implementation and transmission mechanisms in the Euro area.”,
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

192. DE BRUYNE Karolien (07/06/2004)
“Essays in the location of economic activity”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

193. ADEM Jan (25/06/2004)
“Mathematical programming approaches for the supervised classification problem.”,
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

194. LEROUGE Davy (08/07/2004)
“Predicting Product Preferences : the effect of internal and external cues.”,
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

195. VANDENBROECK Katleen (16/07/2004)
“Essays on output growth, social learning and land allocation in agriculture : micro-evidence from Ethiopia and Tanzania”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

196. GRIMALDI Maria (03/09/004)
“The exchange rate, heterogeneity of agents and bounded rationality”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

197. SMEDTS Kristien (26/10/2004)
“Financial integration in EMU in the framework of the no-arbitrage theory”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

198. KOEVOETS Wim (12/11/2004)
“Essays on Unions, Wages and Employment”
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

199. CALLENS Marc (22/11/2004)
“Essays on multilevel logistic Regression”
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

200. RUGGOO Arvind (13/12/2004)
“Two stage designs robust to model uncertainty”
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2004.

201. HOORELBEKE Dirk (28/01/2005)
”Bootstrap and Pivoting Techniques for Testing Multiple Hypotheses.”
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

202. ROUSSEAU Sandra (17/02/2005)
“Selecting Environmental Policy Instruments in the Presence of Incomplete Compiance”,
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

203. VAN DER MEULEN Sofie (17/02/2005)
“Quality of Financial Statements : Impact of the external auditor and applied accounting standards”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

204. DIMOVA Ralitza (21/02/2005)
“Winners and Losers during Structural Reform and Crisis : the Bulgarian Labour Market Perspective”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

205. DARKIEWICZ Grzegorz (28/02/2005)
“Value-at-risk in Insurance and Finance : the Comonotonicity Approach”
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

206. DE MOOR Lieven (20/05/2005)
“The Structure of International Stock Returns : Size, Country and Sector Effects in Capital Asset Pricing”
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

207. EVERAERT Greetje (27/06/2005)
“Soft Budget Constraints and Trade Policies : The Role of Institutional and External Constraints”
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

208. SIMON Steven (06/07/2005)
“The Modeling and Valuation of complex Derivatives : the Impact of the Choice of the term structure model”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

209. MOONEN Linda (23/09/2005)
“Algorithms for some graph-theoretical optimization problems”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

210. COUCKE Kristien (21/09/2005)
“Firm and industry adjustment under de-industrialisation and globalization of the Belgian economy”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

211. DECAMPS MARC (21/10/2005)
“Some actuarial and financial applications of generalized diffusion processes”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

212. KIM HELENA (29/11/2005)
“Escalation games: an instrument to analyze conflicts. The strategic approach to the bargaining problem”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2005.

213. GERMENJI ETLEVA (06/01/2006)
“Essays on the economics of emigration from Albania”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

214. BELIEN JEROEN (18/01/2006)
“Exact and heuristic methodologies for scheduling in hospitals: problems, formulations and algorithms”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

215. JOOSSENS KRISTEL (10/02/2006)
“Robust discriminant analysis”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

216. VRANKEN LIESBET (13/02/2006)
“Land markets and production efficiency in transition economies”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

217. VANSTEENKISTE ISABEL (22/02/2006)
“Essays on non-linear modelling in international macroeconomics”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

218. WUYTS Gunther (31/03/2006)
“Essays on the liquidity of financial markets”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

219. DE BLANDER Rembert (28/04/2006)
“Essays on endogeneity and parameter heterogeneity in cross-section and panel data”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

220. DE LOECKER Jan (12/05/2006)
“Industry dynamics and productivity”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

221. LEMMENS Aurélie (12/05/2006)
“Advanced classification and time-series methods in marketing”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

222. VERPOORTEN Marijke (22/05/2006)
“Conflict and survival: an analysis of shocks, coping strategies and economic mobility in Rwanda, 1990-2002”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

223. BOSMANS Kristof (26/05/2006)
“Measuring economic inequality and inequality aversion”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

224. BRENKERS Randy (29/05/2006)
“Policy reform in a market with differentiated products: applications from the car market”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

225. BRUYNEEL Sabrina (02/06/2006)
“Self-econtrol depletion: Mechanisms and its effects on consumer behavior”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

226. FAEMS Dries (09/06/2006)
“Collaboration for innovation: Processes of governance and learning”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

227. BRIERS Barbara (28/06/2006)
“Countering the scrooge in each of us: on the marketing of cooperative behavior”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

228. ZANONI Patrizia (04/07/2006)
“Beyond demography: Essays on diversity in organizations”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

229. VAN DEN ABBEELE Alexandra (11/09/2006)
“Management control of interfirm relations: the role of information”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

230. DEWAELHEYNS Nico (18/09/2006)
“Essays on internal capital markets, bankruptcy and bankruptcy reform”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

231. RINALDI Laura (19/09/2006)
“Essays on card payments and household debt”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

232. DUTORDOIR Marie (22/09/2006)
“Determinants and stock price effects of Western European convertible debt offerings: an empirical analysis”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

233. LYKOGIANNI Elissavet (20/09/2006)
“Essays on strategic decisions of multinational enterprises: R&D decentralization, technology transfers and modes of foreign entry”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

234. ZOU Jianglei (03/10/2006)
“Inter-firm ties, plant networks, and multinational firms: essays on FDI and trade by Japanse firms.”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

235. GEYSKENS Kelly (12/10/2006)
“The ironic effects of food temptations on self-control performance”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

236. BRUYNSEELS Liesbeth (17/10/2006)
“Client strategic actions, going-concern audit opinions and audit reporting errors”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

237. KESSELS Roselinde (23/10/2006)
“Optimal designs for the measurement of consumer preferences”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

238. HUTCHINSON John (25/10/2006)
“The size distribution and growth of firms in transition countries”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

239. RENDERS Annelies (26/10/2006)
“Corporate governance in Europe: The relation with accounting standards choice, performance and benefits of control”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

240. DE WINNE Sophie (30/10/2006)
“Exploring terra incognita: human resource management and firm performance in small and medium-sized businesses”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

241. KADITI Eleni (10/11/2006)
“Foreign direct investments in transition economies”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

242. ANDRIES Petra (17/11/2006)
“Technology-based ventures in emerging industries: the quest for a viable business model”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

243. BOUTE Robert (04/12/2006)
“The impact of replenishment rules with endogenous lead times on supply chain performance”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

244. MAES Johan (20/12/2006)
“Corporate entrepreneurship: an integrative analysis of a resource-based model. Evidence from Flemish enterprises”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

245. GOOSSENS Dries (20/12/2006)
“Exact methods for combinatorial auctions”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

246. GOETHALS Frank (22/12/2006)
“Classifying and assessing extended enterprise integration approaches”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

247. VAN DE VONDER Stijn (22/12/2006)
“Proactive-reactive procedures for robust project scheduling”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2006.

248. SAVEYN Bert (27/02/2007)
“Environmental policy in a federal state”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.

249. CLEEREN Kathleen (13/03/2007)
“Essays on competitive structure and product-harm crises”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.

250. THUYSBAERT Bram (27/04/2007)
“Econometric essays on the measurement of poverty”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.

251. DE BACKER Manu (07/05/2007)
“The use of Petri net theory for business process verification”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.

252. MILLET Kobe (15/05/2007)
“Prenatal testosterone, personality, and economic behavior”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.

253. HUYSMANS Johan (13/06/2007)
“Comprehensible predictive models: New methods and insights”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.

254. FRANCKEN Nathalie (26/06/2007)
“Mass Media, Government Policies and Economic Development: Evidence from Madagascar”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.

255. SCHOUBBEN Frederiek (02/07/2007)
“The impact of a stock listing on the determinants of firm performance and investment policy”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.

256. DELHAYE Eef (04/07/2007)
“Economic analysis of traffic safety”.
Leuven, K.U.Leuven, Faculteit Economische en Toegepaste Economische Wetenschappen, 2007.