# Behavioural Adaptation, Risk Compensation, Risk Homeostasis and Moral Hazard in Traffic Safety

## Literature Review

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# Samenvatting

De veiligheidsverhogende effecten van verkeersveiligheidsmaatregelen worden soms afgevlakt door gedragsadaptatie van weggebruikers. Dit fenomeen is empirisch aangetoond voor een reeks verkeersveiligheidsmaatregelen, zowel op het gedragsniveau van de weggebruiker, als op het geaggregeerde ongevallenniveau. Deze literatuurstudie geeft de theoretische grondslagen en empirische toepassingen van gedragsadaptatie weer.

## Abstract

The intended effects of road-safety measures are sometimes offset by behavioural adaptation among road users. This phenomenon has been empirically demonstrated for several road safety measures, both on an individual behavioural level, and on an aggregated accident-risk level. This literature review presents the theoretical foundation and empirical applications of behavioural adaptation.

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# 1. INTRODUCTION

Suppose that engineers can demonstrate that airbags reduce the injury risk in a car accident by 25 percent for any given frequency and severity of accidents, would the installation of these devices necessarily reduce the fatality rate by 25 percent? The answer depends upon the response of drivers to the increased protection from dangerous accidents. If they increase their driving intensity (speed, recklessness, driving while intoxicated, …), they may realize substantially less than the 25 percent predicted reduction in fatalities. Such offsetting behaviour is not irrational: it merely represents a substitution of the marginal benefits of driving intensity for the reduced marginal cost of risk (Crandall and Graham, 1984).

Any system, which aims to increase the safety on the roads, might be less effective as expected or even may lead to more accidents. These effects in traffic situations have been recognised for a long time. In a paper written more than half a century ago entitled 'A theoretical field-analysis of automobile driving,' Gibson and Crooks (1938, p. 458 in Evans, 2004) wrote:

*“More efficient brakes on an automobile will not in themselves make driving the automobile any safer. Better brakes will reduce the absolute size of the minimum stopping zone, it is true, but the driver soon learns this new zone and, since it is his field-zone ratio which remains constant, he allows only the same relative margin between field and zone as before”.*

Several studies of driving behaviour have suggested that individuals will react to changes in driving conditions in a compensatory fashion such that riskier behaviours result from perceptions that the environment has become safer. (Stetzer and Hofmann,1996). For policymakers, however, the key question is how much offsetting behaviour actually occurs. As Peltzman (1975) acknowledges, offsetting behaviour could be trivial or substantial. Indeed, the amount varies between road safety measures. Furthermore, in evaluating whether individuals display compensating behaviour in response to safety interventions, not all persons subject to the intervention will necessarily display compensating behaviour, even if this hypothesis is correct.

This literature review tries to cluster the theoretical and empirical literature, concerning offsetting behaviour in the road safety setting. In the first section, the concepts, regarding offsetting behaviour are elaborated. The second section describes the empirical evidence.

# 2. Behavioural Adaptation, Risk Compensation, Risk Homeostasis and moral hazard

## 2.1 Concepts

Risk compensation is the term given to a theory which tries to understand the behaviour of people in potentially hazardous activities. In the context of the road user, risk compensation refers to the tendency of road users to compensate for changes in the road system that are perceived as improving safety by adapting behaviour (Elvik and Vaa, 2004). So measures, designed to improve traffic safety, may bring along negative consequences in a way that individuals increase the riskiness of their driving behaviour because they feel safer (Dulisse, 1997).

A term, closely related to risk compensation, is 'behavioural adaptation'. Behavioural adaptation is a wider term referring to all behavioural changes triggered by a safety measure (OECD, 1997). Strictly spoken, this includes all positive and negative behavioural changes induced by road safety measures. Nevertheless, the emphasis is primarily put on the negative aspects of this phenomenon (Saad, 2004).

The insurance industry uses the term 'moral hazard' to describe insurance (contract) induced changes in driving behaviour (Evans, 2004). Insurance protects against serious financial consequences of road accidents. This protection may imply that road accidents are perceived to be less serious than they otherwise would have been, so that road users become less careful. On the basis of this, it has been claimed that the existence of automobile insurance in itself adversely affects road safety (Elvik & Vaa, 2004).

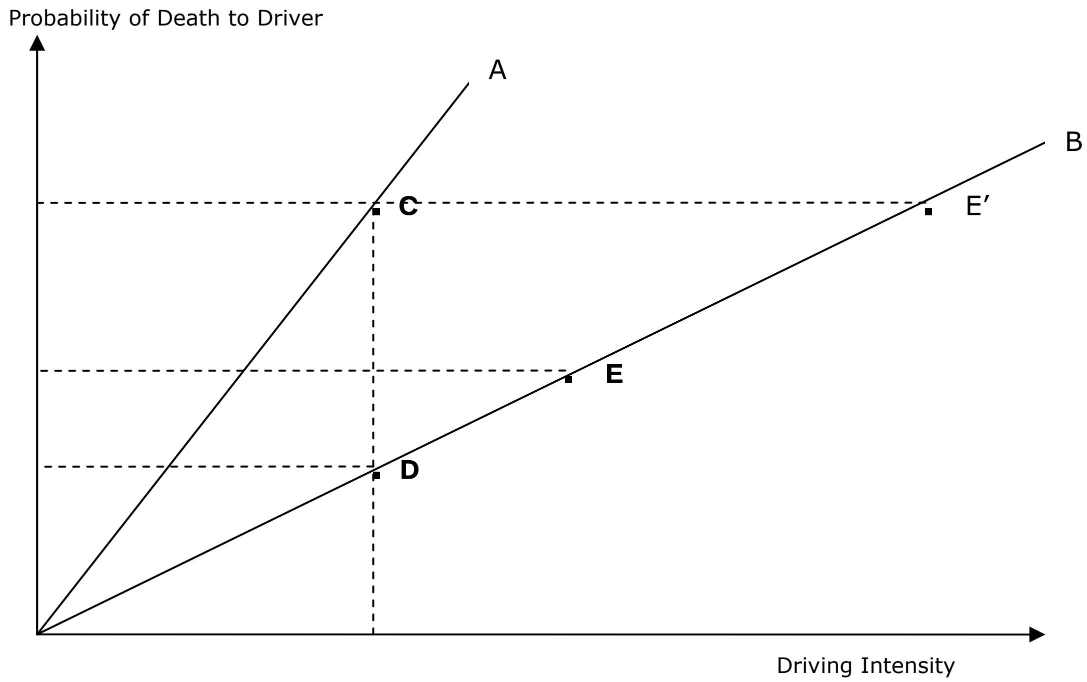
## 2.2 Theoretical backgrounds

### *2.2.1 An economic approach to risk compensation – Peltzman's theory*

Peltzman (1975) evaluated the effects of regulation of mandatory vehicle safety devices in the 1960s. He based his research on time-series and cross-sectional accident data from 1947 to 1972 in the United States. The main conclusion of his work is that, in contrast with the intent of safety regulation, it has had no effect on the highway death rate. Furthermore, he found evidence of a shift of the burden of accidents from drivers to pedestrians, and of an increase in property-damage accidents.

In order to support his findings, Peltzman (1975) created an economic model of risk compensation in which the behaviour of drivers is assumed to be completely rational. The basis is a choice model of decision theory principles with competing demands of safety risk and driving intensity (i.e. more speed, thrills, recklessness, …). Figure 1 displays the relationship between these two factors. Ray A is the original trade-off rate between 'the probability of death' and 'driving intensity'. Essentially, more driving intensity is associated with forgoing some safety. When vehicle safety devices are available or mandated, the risk price of driving intensity is lowered (resulting in a turnover of the trade-off rate ray, ray B). Holding driving intensity constant, the magnitude of the productivity effect of the devices could be represented as the distance between points C and D in figure 1. However, treating driving intensity as a normal good, Peltzman (1975) states that the consumption equilibrium rather lies in point E than D. He claims that lowering the cost of driving intensity (by lowering the probability of death given an accident) will lead to an increase of consumption and thereby enlarging the safety risk. Note that this hypothesis of risk compensation does not imply that drivers necessarily impose themselves to more risk (i.e. a probability of death higher than at point C) as a consequence of a safety intervention, but it implies that the effect of the safety intervention is partly (or completely) offset by an increase in risk above the risk at point D. The degree at which this offsetting behaviour is situated is not predicted by Peltzman.

**Figure 1: Risk Compensation according to Peltzman (1975)**

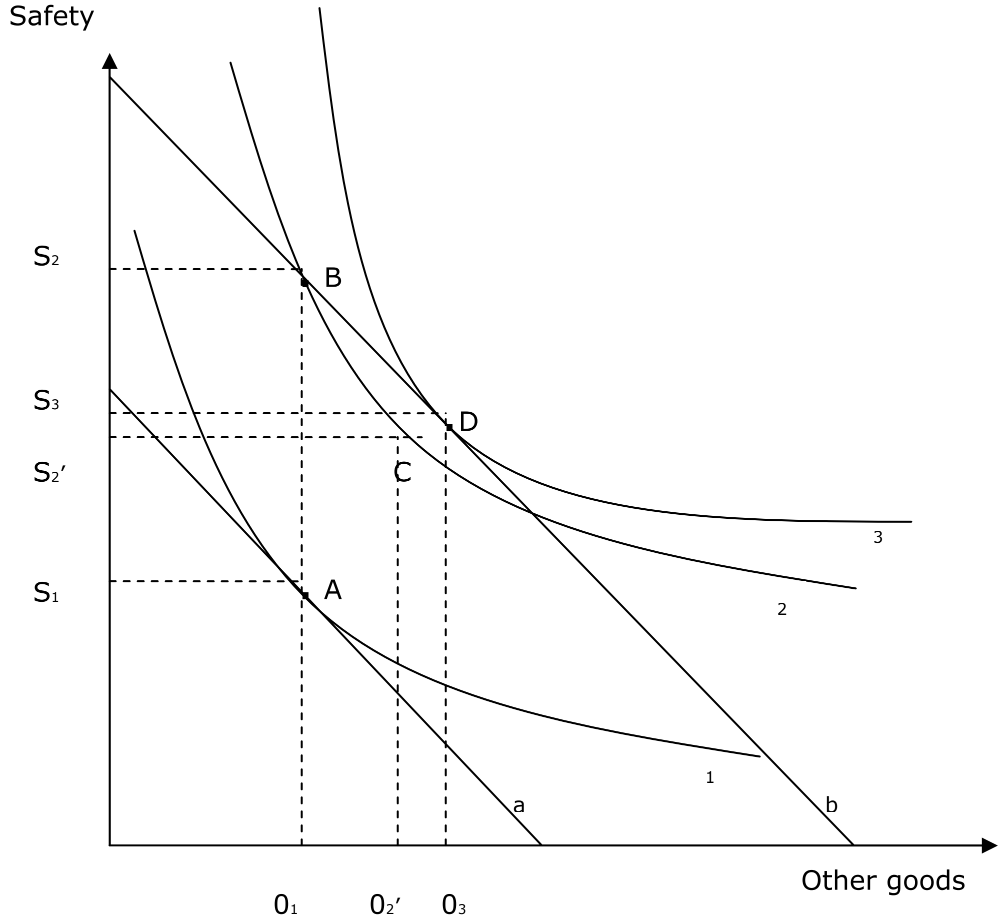



Source: Adapted from Peltzman (1975), p.681

Peltzman's results are in line with his hypotheses of risk compensation. Although he did not find an increase of death rate after the mandatory safety devices' installation, he encountered higher risks to pedestrians and bikers. He argues that, following automobile regulation, drivers increase their driving intensity through for example higher driving speeds. Although these new speeds do not counteract the effects of the safety intervention, these can endanger other road users not benefiting from the automobile safety regulations.

A more thorough elaboration of driver behaviour in case of risk compensation, is described by Dulisse (1997). He points out that driver behaviour may be inferred from an appropriately chosen utility optimization problem. Figure 2 presents the theoretical foundation of this choice theory model. Suppose that an individual has to trade off between two goods: Safety (S) at the one hand and some other good (O) at the other hand. For example, O could represent driving speed in the sense that higher driving speed (and thus less travel time) decreases the corresponding safety level[1].

**Figure 2: Risk compensation: choice theory between safety and other goods**




Source: Dulisse (1997), p. 291

Curve 1 represents the combinations of S and O that yield equal satisfaction. In other words, those are the combinations among which the individual is indifferent. Which bundle the individual actually chooses, depends on the trade-off rate of the two 'goods'. The point at which the budget restriction line[2] (represented by the straight line a) is

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[1] In general, O could be a composite of many other goods. Orr (1982, in Noland, 1995) expanded Peltzman's notion of 'driving intensity' to include other factors as well. He incorporated other changes in behaviour that could result from increases in safety regulations. For example, allowing small children to stand in the front seat of automobiles, an increased willingness to allow teenagers to drive, more driving during hazardous weather, and more tired or drunken driving.

[2] The budget restriction line shows all the combinations of the two goods that a consumer can buy, if she spends a fixed amount of money (given her money income and the prices of the goods she purchases) (Lipsey and Courant, 1996).

tangent to the preferences, generates optimal satisfaction (utility). In this point (A), the individual 'consumes' $S_1$ amount of safety and $O_1$ amount of some other good.

Now suppose that as a consequence of a safety intervention (such as mandatory safety devices), without changing any other behaviours, this individual receives an increase of the amount of safety without reducing the amount of the other goods he possesses (point B). This process takes form in a parallel upwards shift of the budget restriction line (line b). However, the combination of safety ($S_2 > S_1$) and the other good $O_1$ is not an optimal decision according to the individual's indifference mapping. By trading away enough safety in exchange for the other good (so more thrills, speeding, …), the driver reaches the point D, where satisfaction is optimal, given the trade-off rate[3].

Note that in this graphical representation what has happened, is that the individual is willing to exchange part of the increase in safety generated by the intervention. Thus, the hypothesis of risk compensation does not imply that drivers expose themselves to more risk as a consequence of the safety intervention (Dulisse, 1997). It implies that they will choose actions that are riskier than the action previously chosen (from $S_2$ to $S_3$). Even with the riskier actions, it is likely that the individual will have more safety than before the intervention ($S_3 > S_1$). Obviously, the extent of the risk compensation effect is dependent on the preferences of the individual driver. Some persons will be highly affected by a road safety measures in terms of adapting behaviour, while others will be not.

[3] Point D lies on a higher indifference curve than point B and thus generating more satisfaction to the driver.

### *2.2.2 The risk homeostasis theory of Wilde*

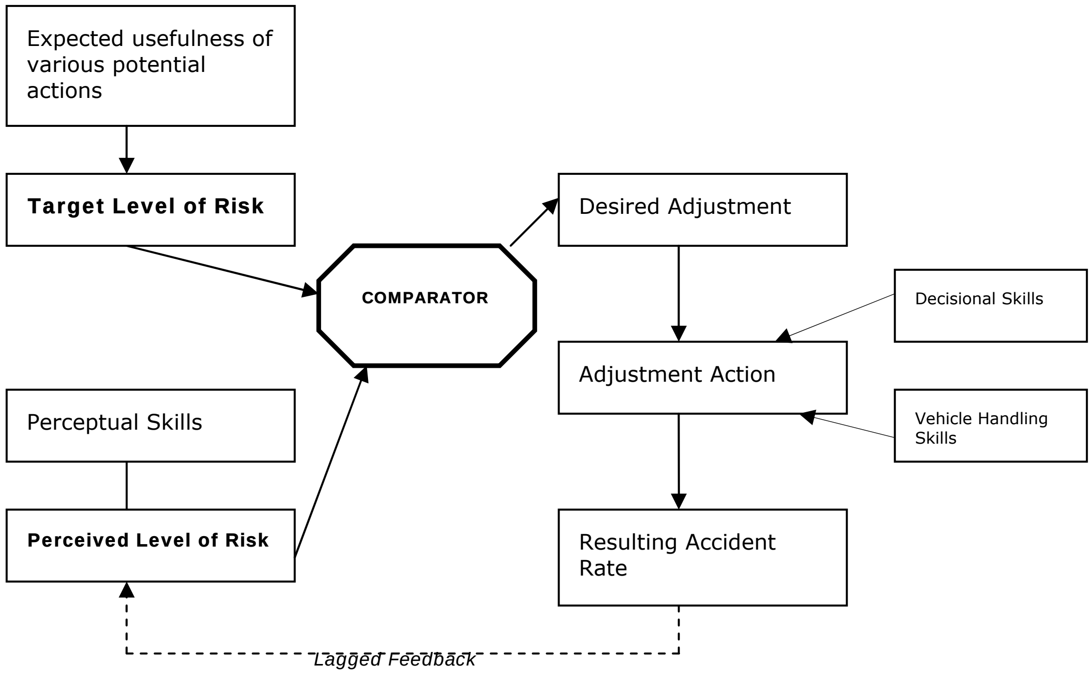
In addition to Peltzman's theory of risk compensation, Wilde (1994) elaborated a more psychological model (risk homeostasis theory, RHT) to explain why safety interventions have not produced long-term decreases in death rates. In essence, the risk homeostasis theory contains the following idea:

*"People alter their behaviour in response to the implementation of health and safety measures, but the riskiness of the way they behave will not change, unless those measures are capable of motivating people to alter the amount of risk they are willing to incur (=target level of risk)". (Wilde, 1994)*

According to Wilde (1994), an individual is acting as a homeostatically controlled self-regulation process. In any activity, people continuously check the amount of risk they feel exposed to (=subjective risk). They compare this with the amount of risk they are willing to accept (= target risk), and try to reduce any difference between the two to zero. Thus, if the level of subjectively experienced risk is lower than is acceptable (for example due to a change in the driving environment), people tend to engage in actions that increase their exposure to risk. So, unless the target level of risk changes[4], no permanent changes in safety can be attained. Wilde's homeostatic model, that relates accident rate to driver behaviour, is presented in figure 3.

[4] Wilde (2002) proposes four approaches to reducing the target level of risk for drivers, i.e. (1) rewarding particular safe behaviours, (2) rewarding drivers who have not crashed, (3) punishing particular unsafe behaviours, and (4) punishing drivers for having crashed.

**Figure 3: Homeostatic model comparing the driver's behaviour, the accident rate and the level of target risk**




Source: Wilde (1982), p.212

As Wilde (1994) believes that the equilibrium between estimated and accepted risks is maintained through risk homeostasis, traffic safety only increases or decreases during the imbalance phase. Overall, he states that the number of accidents in any given country only depends on the accident rate which the population is willing to tolerate, and not on the specific measures taken, at least not over a longer period of time (Wilde, 1994). The Risk Homeostasis Theory challenges the foundations of injury prevention strategies. It holds that the only effective safety measures are those that alter the desired risk level of the drivers. Anything that merely modifies the environment or that regulates driver behaviour without affecting the target risk level, is useless (Hedlund, 2000).

While Peltzman's theory does not predict the magnitude of risk compensatory behaviour, in the risk homoeostasis theory the compensation effect is virtually complete. Returning to figure 1, Wilde predicts that the new equilibrium lies in point E', holding the target risk constant.

The typical example, invoked to prove the risk compensation theory, is the Swedish experience with the change from left hand to right hand traffic in 1967 (Wilde and Robertson, 2002). The change was followed by an immediate and major reduction in the per capita traffic fatalities and injury rate. A higher level of risk was perceived, thus the drivers compensated by driving very carefully, until they got used to the new situation. Over a period of one year Swedish accident rates returned to the previous levels (Trimpop, 1996).

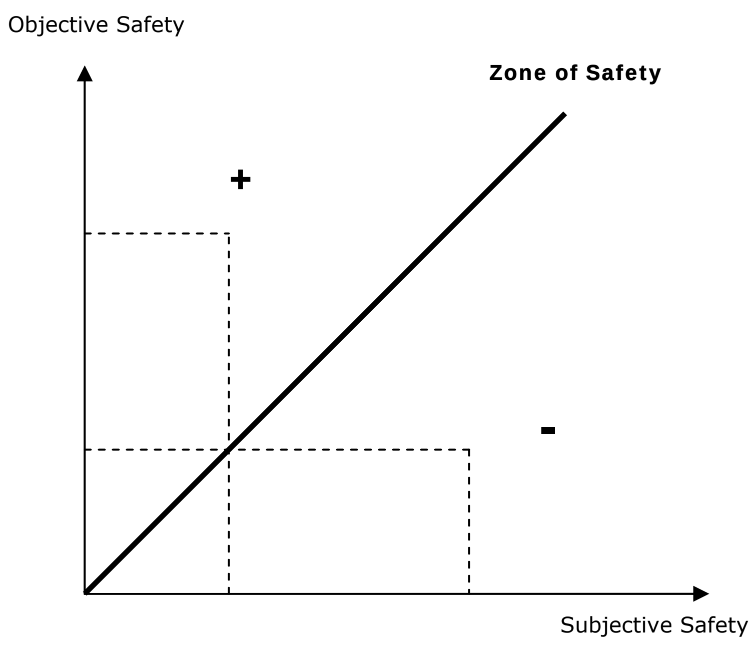
The risk homeostasis theory has lead to much controversy in both theoretical contributions as empirical investigations. The main allegations are based on methodological issues. Wilde’s theory does not explain in detail how individuals set their target levels of risk and subjective risk, nor does it state how to measure target level of risk empirically (Elvik, 2004). Furthermore, since Wilde’s hypothesis is constituted at the level of the social system by the driver population (i.e. accident rate), this principle is not easily transferred to the individual level, where adaptation motives play a crucial role (Trimpop, 1996). But although Wilde’s theory is controversial, there seems to be a general agreement in the literature that road users do adapt their behaviour to certain risk-reducing measures (Assum et al., 1999).

### *2.2.3 Model of objective and subjective safety - Klebelsberg*

Another theory which leads to similar conclusions as the risk compensation and the risk homeostasis theory, is the model of objective and subjective safety of Klebelsberg (1982, quoted in OECD, 1997). Klebelsberg argues that there is a dialectic relationship between safety as it actually exists ('objective safety'), and safety experienced by people in different situations ('subjective safety').

The model shows that traffic safety increases with improvements in objective safety, without commensurate increases in subjective safety (**figure 4**). It decreases if there is an increase in subjective safety without objective safety increasing in at least the same proportion. Thus, according to this model, many safety problems result from a discrepancy between objective and subjective risk. For example, the improvement of the visibility at a road junction (i.e. higher objective safety) can produce higher speeds at this crossing (because of the resulting increase in subjective safety) and as a consequence, the accident rate may increase as a result of this safety measure.

**Figure 4: The model of objective and subjective safety (Klebelsberg, 1982)**




Source: OECD (1997), p.64

### 2.2.4 Moral hazard

The concept of moral hazard was introduced to the economic literature by Arrow (1963) and Pauly (1968). Moral hazard arises from asymmetric information. In any kind of transaction between parties, moral hazard exists when one party to a transaction has both the incentive and the ability to shift costs onto the other party (Lipsey et al., 1996).

Insurance contracts are typical market transactions from which moral hazard arises. In case of automobile insurance, the insurer does not know the true nature of an individual's driving skills and motivation to prevent losses. Consequently, the insured exploits this lack of information and changes his or her driving behaviour to maximize individual benefits. Moral hazard is thus defined as the effect of insurance on the choice of self-protection activities by the insured when the insurer cannot observe these activities. As a theoretical matter, automobile insurance is believed to have the moral hazard cost of reducing policyholders' incentives to take precautions against the insured loss (Boyer and Dionne, 1989).

An additional distinction should be made between ex ante moral hazard and ex post moral hazard, as there is an important difference between an accident and a claim. Moral hazard is ex ante when the consequence of the policyholder's effort is a decrease in accident probability or severity (and thus representing prevention efforts). Ex post moral hazard refers to the incentives to filing a claim and this is of course also influenced by the form of the insurance contract (Chiappori, 2001). In the context of accident prevention, the only point of interest is the 'true' moral hazard effect, i.e. ex ante moral hazard. Therefore, in this literature review, moral hazard refers to the ex ante effect.

## 2.3 Factors influencing offsetting behaviour

### *2.3.1 Hypotheses of behavioural adaptation of Bjørnskau and Amundsen, Elvik*

According to Elvik (2004), the Risk Homeostasis and the risk compensation theory are too vague in explaining the specific underlying behavioural mechanisms, which makes empirical testing extremely difficult. He argues that what is needed, is a set of more specific, yet general hypotheses concerning risk adaptation. In his work, Elvik (2004) proposes six factors (adapted from Bjørnskau and Amundsen, 2003) as influencing behavioural adaptation. These are:

(1) More easily noticed safety measures are more likely to lead to behavioural adaptation;

(2) If there is antecedent behavioural adaptation to a certain risk factor, then behavioural adaptation to measures, intended to reduce that risk factor, is more likely to occur[5];

(3) The greater the engineering effect[6], the more likely is behavioural adaptation to arise;

(4) Measures that primarily reduce the probability of an accident are more likely to lead to behavioural adaptation than measures that reduce injury severity[7];

(5) The smaller the likely size of material damage (closely related to vehicle size), the greater the behavioural adaptation effect;

(6) If additional utility can be gained from changing behaviour, the more likely behavioural adaptation will occur.

Several other researchers have taken up one or more of these factors in their conclusions as these are decisive in the context of risk compensation. For example, Lund and O'Neil (1986) first suggested that offsetting behaviour is more likely to occur for accident-reducing rather than for injury-reducing measures. Because changes that reduce the likelihood of a crash also often provide direct and immediate feedback, drivers may

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[5] For example: if road users have lowered their speed or increased their attention because the road is narrow, they will increase their speed or reduce their attention when the road is widened

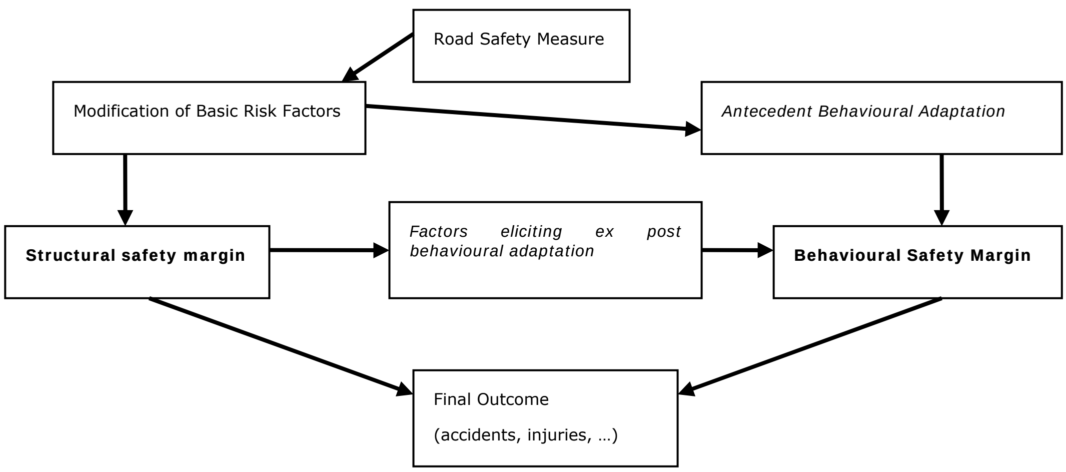
[6] The size of the engineering effect refers to the size of the changes made in, for example, sight distance, separation between incompatible road users or complexity of the road and traffic environment.

[7] For example, behavioural adaptation is more likely to occur in the presence of antilock brakes than of airbags.

change their behaviour. In case of changes that increase occupant protection, usually no direct and immediate feedback is presented and, therefore, should have no effect on driving behaviour. The statistical analyses, conducted by Lund and O'Neil (1986), are consistent with this viewpoint. Also Sagberg et al. (1997) reached the same conclusion. According to their analysis, accident-reducing measures like antilock braking systems are compensated for among road users to a larger extent than injury-reducing measures like an airbag. Harless and Hoffer (2003), finally, concluded that there is stronger support for the offsetting behaviour hypothesis when studded snow tires are adopted or when weather or lighting affect driving conditions (and hence the likelihood of an accident). Evidence of risk compensation is weaker or absent altogether for injury-reducing measures.

As an extension of the previous described factors, Elvik (2004) proposed a model of causal chains that generates the effect of road safety measures (Figure 5). Road safety measures are intended to modify traffic accident risks. The consequences of the changes in the risk factors can be termed the 'structural safety margin'[8]. Dependent on the kind of risk factor, antecedent behavioural adaptation can occur (see factor (2)). Furthermore, properties of changes in the structural safety margin, due to certain road safety measures, influence the likelihood that behavioural adaptation to the measures will take place. The result of behavioural adaptation is termed the 'behavioural safety margin'. This concept refers to how road users assess their safety margin when travelling.

**Figure 5: Model of causal chain that generates the effect of road safety measures**



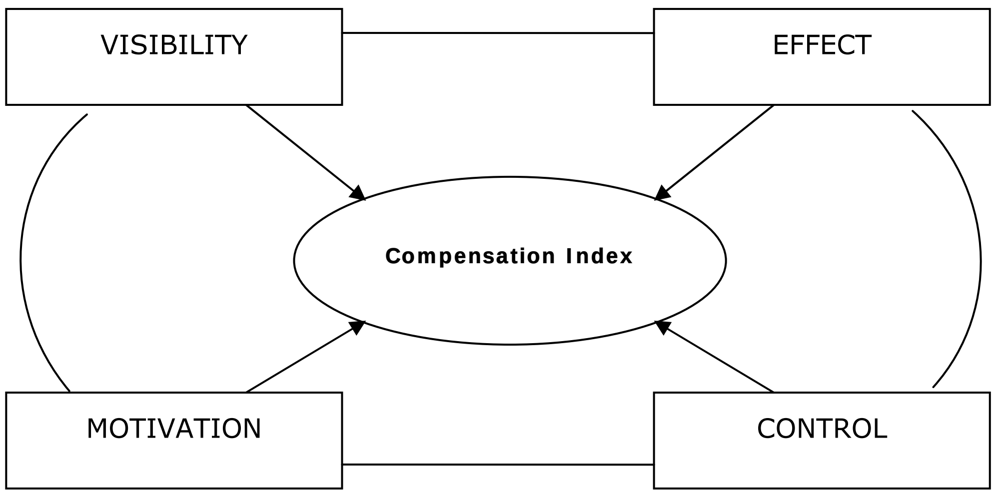

Source: Elvik (2004), p.845

[8] Examples of the structural safety margin of the road system are sight distance, speed, time to collision, … .

### 2.3.2 *The compensation index of Hedlund*

In addition to the set of hypotheses of risk adaptation from Bjørnskau and Amundsen (2003), described above, Hedlund (2000) also elaborated a useful framework of influencing elements. He constructed the so-called 'compensation index' in order to evaluate whether behavioural adaptation is likely to occur for a given safety measure. This index is composed of four factors, interacting with each other (Figure 6).

**Figure 6: The compensation index of Hedlund (2000)**




Source: Adapted from Hedlund (2000)

- **Visibility**: If changes to the road safety system are very obvious to the road user, behavioural adaptation is more likely to occur, especially if these changes affect performance through direct feedback (for example, vehicle brakes and studded tires). Hedlund (2000) suggests the following rule of thumb: *"If a safety measure is not easily noticed, than the road user is not likely to compensate for it."*
- **Effect**: The second factor, influencing the existence of compensating behaviour, describes to what extent the road user is affected by a road safety measure, both physically and mentally. This factor has several dimensions. First, a measure can have an effect on the physical performance of the driving task. For example, helmets can be physically uncomfortable for some motorcyclists, improved braking systems make the driving task easier, … . Second, the attitude of road drivers can be influenced. And finally, the degree in which the change affects the perception of risk, is significant. At the one hand, there will be road users who clearly feel safer after

the introduction of a certain road safety measure and at the other hand, there will be who do not. Hedlund (2000) puts forward: *"If a measure does not affect the road user, he will not compensate for it."*

- **Motivation:** This factor is key to most risk compensation theory discussions. It describes motivational background of the road user's behaviour, i.e. preferences, needs, habits, … . It holds that *"if the road user is not motivated to change behaviour, he will not compensate for a safety measure".*

- **Control:** The last factor consists of the degree of freedom that a road user has in changing his behaviour. Essentially, driving allows considerable autonomy. Traffic laws provide nominal control, but since most laws are not enforced rigorously, individual drivers have substantial latitude for their actions and thereby more possibilities in changing their behaviour. According to Hedlund (2000), the following rule applies: *"if driver behaviour is tightly controlled, road users will not act in a compensatory way".*

# 3. EMPIRICAL APPLICATIONS

## 3.1 Introduction

In the next sections, empirical evidence, supporting the concepts of behavioural adaptation, risk compensation, risk homeostasis and moral hazard, related to road safety[9], is presented. Except for risk homeostasis, all other terms, referring to adverse incentive effects, will be used simultaneously in this review. Furthermore, the described research studies provide empirical evidence of behavioural adaptation on the individual behavioural level as well as on the aggregated accident-risk level.

Firstly, the empirical research concerning different types of automobile safety devices and regulation is elaborated. Secondly, findings of adverse incentives caused by environmental changes in the road system are presented. And finally, the adverse effects of automobile insurance and type of insurance contracts on driving behaviour are reported.

[9] Obviously, this literature review does not contain all existing empirical evidence of behavioural adaptation related to the road safety context. For example, literature concerning the influence of driving experience is extensively described in Willems and Cuyvers (2004) and Willems (2005).

## 3.2 Automobile safety devices and regulation

Lave and Weber (1970) first suggested the possibility that mandatory safety devices could lead to risk compensation behaviour. In their research, they concentrated on the benefit-cost analysis of auto safety features on 1968 automobiles. They mentioned a few problems in estimating the probability of injury induced by a device. One of these, is the possibility that an individual will react to the introduction of safety devices by driving more rapidly. Automobile safety features allow the driver to sacrifice some of the increased safety to arrive at his destination faster. They concluded that this behaviour could offset some of the beneficial effects of safety devices.

### *3.2.1 Automobile safety standards in general*[10]

As mentioned in section 2.2.1 (An economic approach to risk compensation – Peltzman's theory), Peltzman (1975) first tested the hypothesis of offsetting consumer behaviour with regard to automobile safety equipment and design, regulated in the United States in 1965. These safety measures include seat belts, energy-absorbing steering columns, penetration-resistant windshields, dual-braking systems and padded instrument panels. He projected the expected accident rates based on accident rates of the pre-regulation period to the present. Variables estimated throughout a double log model of fatalities (rate) included alcohol, youth, speed, accident cost, income and a time trend. From a time-series and cross-section analysis, the same conclusion can be drawn: regulation appears not to have reduced highway fatalities. Peltzman found a shift of accidents from drivers to pedestrians, and of an increase in property-damage accidents.

Following Peltzman (1975), Crandall and Graham (1984) provided some new empirical estimates of the effects of crashworthiness standards established for automobiles after 1965 in the United States. These standards have required the installation of lap shoulder belts, energy-absorbing steering columns, head restraints, padded dashboards, crush-resistant passenger compartments, safer windshield mounting, more secure locks and a variety of other features. Throughout a time-series analysis, Crandall and Graham estimated determinants of passenger car occupant fatalities and pedestrian and bicyclists fatalities in the period 1947-1981. Besides the variables introduced in Peltzmans' model,

[10] For an detailed overview of safety increasing vehicle technology, see Denys (2005, 2006a and 2006b).

they included other determinants such as a measure of the share of miles operated on rural roads, the share of miles driven on limited access highways, the share of truck miles relative to total annual vehicle miles and the average weight of cars on the road. The estimate of the regulation proxy in the pedestrian and bicyclists death model reveals evidence of some offsetting behaviour. However, this estimate is much smaller than that required for an increase in pedestrian-cyclist fatalities to fully offset the decline in occupant deaths. Crandall and Graham concluded that the intrinsic engineering effects of safety devices appear to swap the behavioural response.

### *3.2.2 Mandatory seat belt legislation*

Mandatory seat belt use is intended to ensure a high usage rate[11]. This measure is often regulated because it is known that the use of seat belts affect the probability of being injured when an accident occurs. Elvik and Vaa (2004) summarize the effects of seat belts in accidents reported by several research reports[12]. On average, seat belt usage reduces the probability of being killed by 40-50% for drivers and passengers in the front seat and by about 25% for passengers in the rear seats. The effect on serious injuries is almost as great, while the effect on slight injuries is smaller, around 20-30%. In spite of these encouraging engineering estimates, seat belts have not delivered all the safety benefits that were originally expected of them.

Numerous researchers (Hurst, 1979, quoted in GCC, 2000; Conybeare, 1980, quoted in Noland, 1995; Adams, 1985; Harvey and Durbin, 1986; Streff and Geller, 1988; Asch et al., 1991; Evans and Graham, 1991; Garbacz, 1991; Garbacz, 1992; Shannon and Szatmari, 1994; Janssen, 1994; Dulisse, 1997; Calkins and Zlatoper, 2001) attribute these disappointing results to offsetting behaviour of car drivers induced by the wearing of seat belts. They argue that seat belt laws may be effective at reducing fatalities of car occupants if occupants are induced to wear seat belts at a higher rate than before the law. However, the mandatory use of seat belts encourages car drivers to drive with less care because they feel more protected by the seat belt. Less careful driving has been assumed to lead to more injuries of non-car occupants such as pedestrians and cyclists.

[11] Determinants of seat belt usage are described in Vesentini and Cuyvers (2003). A research study on seat belt usage in Antwerp (Flanders) is conducted by Nuyts and Vesentini (2004 and 2006).

[12] Verlaak (2003a) and Daniëls et al. (2004) also provides an overview of the technical aspects and road safety effects of seat belt use.

The next paragraphs, summarize the results of research in favour of the offsetting hypothesis.

In Great Britain, the seat belt law was introduced on January 31st, 1983. By request of the Parliament, Harvey and Durbin (1986) investigated the changes in casualty rates attributable to the seat belt law. The main data they examined consisted of numbers killed and seriously injured per month for various categories of road users for the period from January 1969 to December 1984. In estimating a structural time series model, explanatory variables included are a car traffic index, a petrol price index, cycle traffic index and a time and seasonal component. Harvey and Durbin found a reduction of 23% of casualties for car drivers. However, looking at the road users indirectly affected by the law, the model gave an increase of fatalities of 7,8% for pedestrians and 13,4% for cyclists. In interpreting the results, the researchers are rather cautious. Not ruling out the possible risk compensation effects, they leave open the possible effects of any other factors involved.

Evans and Graham (1991) explored the American experience with seat-belt-use legislation to test the risk compensation hypothesis. They modelled traffic fatality counts by pooling data from 50 states during the 1975-1987 period. Fixed effects models were estimated, controlling for the following variables: seat-belt legislation (dummy variable), primary and secondary enforcement[13] (dummy variables), unemployment rate and vehicle miles of travel. In total, six models were estimated dependent on the outcome, i.e. car-occupant fatalities, car-occupant fatalities (>21 years), car-occupant fatalities (≤21 years), motorcyclist fatalities, pedestrian fatalities and bicyclist fatalities. The results suggest that mandatory seat belt laws are beneficial for car-occupants. The estimates show a decline of motor vehicle accidents by approximately 8%. As these results are in line with predictions of the effectiveness of seat belts by technologists, Evans and Graham rejected the risk homeostasis hypothesis. Nevertheless, they found some evidence for offsetting behaviour in the motorcyclist, pedestrian and bicyclist counts. In secondary enforcement states, seat belt laws have led to an increase of fatalities of motorcyclists by 3,4%, pedestrians by 8,7% and bicyclists by 14,3%. These results are compatible with Peltzman's own research (1975) of seat belt law effectiveness , i.e. there is a shift of mortality from car-occupants to non-occupants.

[13] There is an important distinction between states that have a primary law and those that have a secondary law. Primary law allows policemen to stop a vehicle and penalize the occupants if they are not in line with the seat belt law. Secondary law, on the contrary, enforces the law only if a vehicle is stopped due to some other traffic violation. It is believed that primary law enforcement is more effective than secondary law.

Like Evans and Graham (1991), Calkins and Zlatoper (2001) estimated the impact of primary and secondary seat belt laws on highway safety in 48 American States. They used regression analysis and two years (1988 and 1997) of state-level data to test for the presence of offsetting behaviour by estimating models explaining total and non-occupant motor vehicle deaths. Besides the indication of the seat belt law, they accounted for several other factors, generally acknowledged as being determinants of highway fatalities (i.e. income, speed limit, population density, alcohol consumption, % youngsters, working population, temperature, share of urban vehicle miles, road expenditure). The results of their analyses are suggestive of and consistent with the risk compensation hypothesis. The 1988 results indicate that primary, and to a lesser extent secondary, seat belt laws are associated with greater total and non-occupant deaths. Although not as pronounced, the 1997 results are for the most part consistent with offsetting behaviour.

The first study that incorporates time series on seat belt usage rates, instead of a seat belt law dummy variable, was done by Garbacz (1991). He evaluated the impact of the New Zealand seat belt law during the period 1960-1985. Estimations of fatality models[14] (with independent variables for seat belt usage, income, speed, alcohol, distance travelled and a time trend) suggest support for the concept of offsetting behaviour. The estimates of seat belt usage rates for the model which includes all fatalities are about half the size of the estimates in the occupant model, representing only occupants deaths of motor vehicles. These results imply that there is an offsetting effect due to an increase of non-occupant fatalities. A similar study of Garbacz (1990), using cross-sectional instead of time series data, revealed offsetting behaviour in the United States.

Garbacz (1992) also carried out a test of offsetting behaviour in regard to mandated seat belt use in the United States. He estimated a logarithmic cross-sectional model of occupant and non-occupant fatalities in 1987, that incorporated the following explanatory variables: seat belt law, disposable income per capita, speed (percentage of vehicles travelling between 55 and 65 miles per hour), alcohol consumption per capita, share of urban population and miles of vehicle travel. In the model of occupant and total vehicle deaths (occupant and non-occupant) no statistically significant effect is found for the seat belt legislation. However, regarding only non-occupant fatalities, a positive and

[14] In total, Garbacz (1991) estimated 12 fatality models (total, car occupant and non-occupant models with linear and logarithmic form and with and without the speed variable).

significant coefficient is reported. Since the total model did show no effect, it might be argued that the total model incorporates some favourable occupant effect which is offset by the unfavourable non-occupant effect. This reasoning would be in line with risk compensatory behaviour.

Research on British data involving mandatory safety-belt legislation, was first conducted by Adams (1985, quoted in Dulisse, 1997). A comparison was made of pedestrian and cyclist injuries before and after mandatory safety-belt legislation for two classes of vehicles: vehicles covered by the law and vehicles not covered by the law. Adams found an increased proportion of fatal crashes in the group of vehicles covered by the law. The same British data were used by Shannon and Szatmari (1994 in Dulisse, 1997) to test the hypothesis of risk compensation. They extended Adams' research by adjusting his model for differences in road type, victims age and vehicle mileage. Controlling for road type and age did not change Adams' results. However, adjusting for differences in exposure partly eliminated the increase in casualties of pedestrians and cyclists. Dulisse (1997) re-examined both studies and argued that these underestimated the risk compensation effect of seat-belt legislation. According to Dulisse, the previous results were biased due to methodological issues concerning the inclusion of irrelevant data[15]. His work suggests that the British data are consistent with a risk compensation effect of 7-13 percent (i.e. an increase of injured pedestrians and cyclists).

Risa (2001) explored a Norwegian data set to test whether adverse incentive effects exist in response to seat belt legislation.  These data consist of pooled cross section and yearly time series of automobile drivers, motorcyclists, and pedestrians that have been killed or injured in Norwegian counties in 1980-1986. Following Garbacz (1991), Risa (2001) also uses information on actual seat belt wearing rates. Furthermore, his model contains also information on technical standards of automobiles, technical standards of roads, density of automobiles in a county and attitudes towards risk (i.e. age and sex). Again different models were estimated dependent on the type of road user. In contrast with the research of Evans and Graham (1991) and Garbacz (1992), Risa found positive and significant estimates of seat belt use for all types of road users. Although it is unusual to encounter a positive relationship between seat belt use and injured automobile drivers, the risk compensation effect on drivers is captured because the Norwegian data set contains also information on the more slight injuries.

[15] A more detailed description of methodological issues in testing the hypothesis of risk compensation can be found in Dulisse (1997).

Many other researchers found some evidence on the behavioural adaptation hypothesis attributed to the wearing of seat belts. Hurst (1979, quoted in GCC, 2000) reported that car occupant fatalities in New Zealand rose after the adoption of mandatory seat belt law, accompanied with a considerable increase of fatalities of other road users. In Australia, Conybeare (1980, quoted in Noland, 1995) found a significant increase in non-occupant fatalities and a less than expected decline in occupant fatalities. The Isles report (1981, in GCC, 2000) described a study on the effects of seat belt laws in Sweden, West Germany, Denmark, Spain, Belgium, Finland, the Netherlands and Norway. In this study, the United Kingdom and Italy were used as controls for non-seat belt countries. The researchers discovered a predominant effect of increased numbers of injuries to non-car users. Furthermore, they predicted a 11% increase in pedestrian injuries in the event of compulsory seat belt wearing legislation. In a case study in New Jersey, Asch et al. (1991, quoted in Cohen and Einav, 2003) found that, while the number of fatalities per accident decreased after the passage of the mandatory seat belt law, there was a significant increase in the number of accidents.

Unlike the other research reported in this section, Streff and Geller (1988, quoted in Trimpop 1996) and Janssen (1994) tested the risk compensation theory of seat belt wearing under controlled conditions. In a field experiment, set up by Streff and Geller (1988), participants had to ride go-carts on a racing course under conditions of wearing a seat belt or not. The authors found a significant increase in speed for the group that drove first without a seat belt and then put it on. Janssen (1994) investigated various driving behaviours of habitual seat belt wearers and non wearers on a 105 km freeway route in the Netherlands. Increasing speed was found amongst drivers who normally did not use seat belts and who took part in the trial where they were forced to use seat belts. In the follow-up study, the main result was that beginning wearers showed signs of continuing behavioural adaptation in the form of increased speed and increased propensity for close following.

### *3.2.3 Airbags*

Some initial evidence on risk compensation effects of airbag adoption is presented by Hoffer and Millner (1992). The researchers evaluated personal injury insurance claims[16] of twenty-one model cars in which driver side airbags became standard equipment from 1991. If no adverse behavioural responses are in place, they expected insurer losses to decline relatively after airbag adoption. By comparing the relative injury claim frequency for the selected vehicle models during the non-equipped period (1989 or 1990) with their relative claim frequency in 1991 (airbag-equipped), an increase of the injury claim frequency is reported for sixteen of the car models[17]. In addition, for eighteen of the cars, the relative collision (physical damage only) claim frequency increased relative to their performance when the cars were belt equipped[18].

Subsequent to Hoffer and Millner (1992), better statistical techniques were applied to additional loss experience data (Peterson and Hoffer, 1994). In total, the change in injury claims (and collision claims) of 87 car models after airbag adoption is investigated during the 1989-1991 period. Estimation was conducted by regressing the 87 changes relative to a dummy variable for airbag-equipped models and a dummy for other restyling changes. Again, with or without adjusting for restylings, relative claims under personal injury protection coverage for newly airbag-equipped car lines worsened relative to belt-only-equipped models. Similar results were found for absolute collision claims.

As an extension of their research, Peterson et al. (1995[19]) expanded their analysis with injury claim data for two extra periods, i.e. 1992 and 1993. Again their empirical model of change in relative injury claims, consisted in a dummy variable for airbag equipment and a dummy that indicates if a specific car model was made larger or not. Results are consistent with Peltzman's compensation hypothesis. All else constant[20], equipping a vehicle with an airbag increases the relative personal injury claims. This result could be drawn from the estimation of the model for all included years. Looking at the separate years, the results are rather mixed. For 1989-1990 and 1991-1992, introducing airbags

[16] These data are provided by the Highway Loss Data Institute (U.S.)

[17] The probability that random effects would increase the relative frequency is only 2,6 %.

[18] There is a 0,07 % chance that this result could have occurred at random

[19] Part of this research is also reported in Peterson and Hoffer (1996).

[20] Consistent with larger cars being safer, if a model was made larger from one year to the next, personal injury claims fell relative to the average of all vehicles.

increased claim frequency, supporting risk compensation; in 1990-1991 and 1992-1993, there was no effect from the introduction of airbags. Since these results are not sufficient enough, the researchers reported an other analysis with more exclusive evidence of offsetting behaviour of drivers with airbag-equipped cars. This analysis was based on data of fatal accidents in Virginia in 1993. By means of several Bernouilli trials, the researchers found that risk to drivers of airbag-equipped cars in single car crashes is not diminished, that the percentage of occupants killed in single car airbag crashes is unusually high, and that drivers of airbag-equipped cars initiate an unusually large percentage of such crashes. Based on the findings of the analyses of these two independent data sets, Peterson et al. (1995) conclude that airbag-equipped cars tend to be driven more aggressively and that aggressiveness appears to offset the effect of the airbag for the driver and increases the risk of death to others.

### *3.2.4 Antilock Braking Systems (ABS)*

Nowadays, many vehicles are fitted with anti-lock braking systems (ABS). This type of braking system prevents the wheels from locking up under extreme braking conditions. It allows the driver to steer during rapid deceleration, especially on slippery road surfaces (www.ambulancedriving.com). Despite these clear advantages of ABS, some researchers found evidence of risk compensation effects. They argue that drivers may take more risks when driving vehicles fitted with ABS, i.e. following other vehicles more closely, braking later for hazards, driving faster on wet roads, … . In short, ABS may increase the accident risk and even accident severity.

The driving behaviour of 81 Canadian test subjects, who were exposed to both ABS or non ABS braking and who practiced normal or hard braking (emergency-like), was evaluated to determine how drivers might modify their driving behaviour (Grant and Smiley, 1993, quoted in Wilde, 1994). The results indicated that those who were shown the increased control available with ABS drove faster in a curve following task, accelerated faster, and used higher brake pedal forces than others who had not been shown the benefits of ABS. It is concluded that drivers adapt to ABS by driving less safely and therefore the overall safety benefit derived from these systems may be less than expected.

Ascenbrenner and Biehl (1994 in Wilde, 1994 and Trimpop, 1996) studied the behaviour of Munich taxicab drivers in respect to ABS for several years. In this study, a part of the taxi fleet was equipped with ABS. Furthermore, they were of the same make and were identical in all other respects to the cars without ABS. By comparing several events (for example accidents, driving style, …), the researches found important differences between the two groups of taxi drivers in support of the risk compensation theory. The accident involvement rate of the ABS vehicles was not lower, but slightly higher (but not statistical significant). Furthermore, it was found that extreme deceleration occurred more often in vehicles with ABS. Concerning driving style, the researchers reported that drivers of taxis with ABS made sharper turns in curves, were less accurate in their lane-holding behaviour, drove at a shorter forward sight distance and created more traffic conflicts[21]. Finally, the ABS taxis drove faster as compared with the non-ABS taxis. In an extension of their study, Aschenbrenner and Biehl (1994) analysed accidents recorded by the same taxi company during one year. Although no difference in accident or severity rate between ABS and non-ABS vehicles was observed, the ABS taxis had more accidents under slippery driving conditions.

The association between ABS and accident risk involvement in particular classes of crashes, was studied by Evans and Gerrish (1996). Analyses were based on aggregated data of two-vehicle crashes (front and rear impacts) during the 1992-1993 period in five American states. They found that ABS leads to a substantial (32%, ±8%) reduction in the risk that an ABS-equipped vehicle will crash into one it is following on wet roads. However, these benefits are largely offset by a 30% (±14%) increase of the risk of being rear impacted[22]. The overall net effect is estimated at 3% (±8%). Concerning accidents on dry roads, Evans and Gerrish (1996) found more convincing evidence of offsetting behaviour, i.e. ABS-equipped vehicles are more likely to crash into the rear of vehicles they are following when both vehicles are moving. The estimated increase is 23% (±15%). According to the researchers, this suggests an increase of risk taking by drivers of ABS vehicles, either in form of decreased headways or increased travel speed.

More evidence of risk compensation induced by ABS-equipped vehicles, can be found in single-vehicle collisions of various types on dry and wet surfaces . Kahane (1994) found that the beneficial effects of ABS technology in terms of reductions of multi-vehicle

[21] 'Traffic conflicts' is a technical term for a situation in which one or more traffic participants have to take swift action to avoid a collision with another road user.

[22] The most likely explanation of this finding is that the superior braking ability of a lead vehicle will logically put it at a higher risk of being hit by a following vehicle not fitted with ABS (Collard and Mortimer, 1998).

crashes were completely offset by fatal single-vehicle crashes. He observed a 29% increase in fatal single-vehicle collisions on dry roads. With regard to non-fatal single-vehicle crashes, the estimates of increased risk are at 19% (ranging from 15% for frontal impacts with fixed objects to 49% for rollovers). Similar effects in single-vehicle collisions, were found by Hertz et al. (1995): + 24% of rollovers (+ 60% of fatal rollovers), + 36% of side impacts with fixed objects (+ 91% of fatal side impacts)[23].

Farmer et al. (1997) conducted analyses of fatal crash involvement[24] of vehicles equipped with ABS. The vehicles (General Motors) included in the study were selected series and models that switched from ABS not available in one model year to standard in one of the next two model years without any concurrent changes in engineering design[25]. For several types of crashes, a risk ratio was computed as the sum of observed fatal crash involvements after ABS adoption divided by the sum of expected fatal crash involvements[26]. According to their estimates, it seems that antilock brakes are beneficial to non-occupants: the vehicles equipped with ABS were involved in significantly fewer fatal crashes in which occupants of other vehicles, pedestrians, or bicyclists were killed. The researchers attributed these findings to the capability of drivers of ABS-equipped cars to steer around obstacles in the road during hard braking. But, perversely, there has been a corresponding increase in the risk of crashes, fatal to the ABS vehicle occupants. This was particularly pronounced in case of rollovers and run-off-the road crashes, but also in some multiple-vehicle crashes (overall effect for all crashes: +24%). This increase could be owing to the fact that drivers of ABS-equipped cars are exposing themselves to riskier situations.

Sagberg et al. (1997) examined the driving behaviour of taxi drivers between the city and the airport of Oslo, Norway. The study consisted of a linked dataset of behavioural observations by means of on-road video recording and self-reported behaviour in questionnaires. The analysis shows that drivers of cars with ABS tend to compensate by closer following. The taxis with ABS have significantly shorter time headways than those without ABS (i.e. 2,2 versus 2,8 seconds).

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[23] In a more recent study of Hertz (2000), crash data of vehicles, whose owners had selected ABS as an option, were included. Concerning the non-beneficial effects, the only statistically one remaining in the 2000 study was rollovers. However, this increase was still large enough to negate most of the benefits of ABS.

[24] Fatal crash involvement is defined as involvement of the vehicle in a crash that resulted in at least one fatality (occupants or non-occupants) (Farmer et al., 1997).

[25] For example, vehicles that switched to ABS in model year 1992 were analyzed for calendar years 1993-1995 (Farmer et al., 1997).

[26] Expected fatal crash involvements were derived by multiplying the pre-ABS model year fatal crash involvement rates by the post-ABS model year exposure (Farmer et al., 1997).

The effectiveness of ABS in Australia was examined by Delaney and Newstead (2004). On the basis of crash data reported by the police from 1987 to 1998, estimates of changes in absolute crash risk, by crash type associated with ABS, were computed by means of induced exposure methods[27]. The absolute risk of being involved in crashes involving vehicles colliding from adjacent, the same or opposing directions and manoeuvring crashes, is estimated to be lower for ABS equipped vehicles than for non-ABS equipped vehicles. In contrast, the risk of crashes involving a vehicle leaving a straight or curved road section is higher for ABS equipped vehicles than for non-ABS equipped vehicles (i.e. 23,88% and 34,65% greater for off path on straight and on curve crashes respectively). Furthermore, the presence of ABS in a vehicle is associated with a 35,88% increase in the absolute risk of involvement in a run-off-the-road crash. In sum, these increases in risk of ABS equipped vehicles resulted in a net zero change in risk across all crash types.

### *3.2.5 Adaptive Cruise Control (ACC)*

As an added value to the conventional cruise control system (i.e. controlling a vehicle's speed[28] at a driver-chosen level), adaptive cruise control (ACC) is a system that is capable of maintaining a fixed time headway (preset by the driver) behind slower vehicles by adjusting the speed of the car. Although designed as comfort enhancing (i.e. reduced workload for the driver), ACC is likely to have a positive effect on traffic safety if no risk compensation effects are in place. By means of smoother acceleration and deceleration profiles, the system contributes to a more stable traffic flow and hence to a more safe traffic environment (Hoedemaeker and Brookhuis, 1998). In contrast, behavioural adaptation is likely to be associated with the use of ACC because of reduced attention to the driving task. The main behavioural changes observed when studying the impact of ACC are changes in speed, in the safety margins (i.e. time headway or time-to-collision), in lane occupancy and in the frequency of lane change manoeuvres. (Ward et al., 1995; Nilsson, 1995; Stanton et al., 1997; Hoedemaeker and Brookhuis, 1998; Rudin-Brown and Parker, 2004; Saad et al., 2004)

[27] Similar methodology was used in Evans and Gerrish (1996).

[28] For the technical aspects of speed control systems, see Verlaak (2003b).

Hoedemaeker and Brookhuis (1998) investigated driver behaviour in response to ACC systems. In their study, the possible benefits or drawbacks of ACC were assessed by having participants drive in a simulator. The participants were divided in four groups according to their driving style concerning speed (driving fast) and focus (the ability to ignore distractions). The results showed behavioural adaptation with an ACC in terms of higher speed, smaller minimum time headways and larger brake force. In an emergency stop scenario, the average maximum braking was larger and the average minimum time headway was smaller when driving with ACC. The type of driving style group made little difference to these behavioural adaptations. The researchers concluded that the observed behaviours are associated with increased accident likelihood and that one should be cautious about the potential safety of the ACC systems.

In another driving simulator study (Nilsson, 1995, quoted in Hoedemaeker and Brookhuis, 1998), the aims were to investigate effects of ACC use on driver behaviour when drivers were exposed to critical traffic situations. The most critical scenario in terms of safety, was the approach of a stationary queue, a scenario that could not be dealt with by ACC[29]. The results showed that drivers using ACC react too late and collide more often with a stationary queue than unsupported drivers. The researcher suggests that these collisions are due to the driver's expectations that the ACC system would cope with the situation. Although informed about ACC limitations, drivers seem to have problems to identify situations requiring them to take over control. Similar conclusions were drawn in a study of Stanton et al. (1997, quoted in Rudin-Brown and Parker, 2004). Although the researchers found no differences between manual and ACC driving in terms of driving speed or headways, four out of twelve test drivers collided with a lead vehicle when the ACC system failed to operate. Driver's performance seemed to degrade in a critical situation in which drivers had to reclaim control.

Ward et al. (1995, quoted in Saad et al., 2004) conducted a field trial with a prototype ACC. The participants were divided into 2 groups of high and low sensation seekers. The trial consisted of a real driving situation on a major highway in moderate traffic. The researchers found a tendency to drive with shorter time headway with ACC. Drivers also set higher average speed with ACC than they drove without ACC. Furthermore, there was some evidence of poor attention to lane positioning with ACC compared to driving without and the failure to yield to other traffic was more frequently occurring. It was

[29] By design, ACC systems do not detect stationary objects. They also cannot function properly when the laser or radar sensor is obstructed by moisture or debris. Given the potential for drivers to rely on ACC, the ability to quickly resume control in the event of failure or sudden braking manoeuvre is critically important.

concluded that the system was used in a manner that may improve traffic flow and harmonization, but only if higher speeds and shorter headways do not increase the accident rate and severity.

According to the results of a research study by Rudin-Brown and Parker (2004), ACC systems induce behavioural adaptation in drivers. In their research, 18 drivers were under observation on a 6,9 km closed test track using no ACC, ACC with a short headway setting and ACC with a long headway setting. These drivers were selected according personal characteristics such as ‘sensation seeking’ behaviour. Throughout testing, the participants were asked to perform a safety-relevant detection task (i.e. to override the ACC system by pressing the brake pedal when noticing the lead vehicle’s brake lights illumination). The results show that the drivers reacted more slowly and less often within a safe time period (approximately 33% less often) on this task when using ACC. This effect was particularly pronounced in ‘high sensation seekers’. Furthermore, ACC was also associated with impaired lane-keeping performance and high sensation seekers were more deviating within the lane then the other test persons.

## 3.3 Environmental changes and regulation

### 3.3.1 *Road lighting*

In general, road lighting is known to reduce the total number of road accidents as well as the risk of road accidents in darkness (Elvik & Vaa, 2004). According to a systematic review of evaluation studies, installing road lighting on a previously unlit road, is associated with a mean reduction of the number of fatal accidents in darkness of 64%, a mean reduction of injury accidents in darkness of 28%, and a mean reduction of property-damage-only accidents in darkness of 17% (Elvik, 2004). However, in this same review, 19% of the reported effectiveness' estimates indicated an increase of the number of accidents. The researcher concludes that although road lighting in most cases reduces the number of accidents, it is by no means certain that it does so in every case. Moreover, it could be possible that the engineering effects of road lighting are systematically reduced by risk compensating behaviour of the road users.

The possible risk compensation for road lighting was investigated on a section of a route in Norway, before and after[30] road lighting was installed (Assum et al., 1999). Data were collected by means of radar, video and questionnaires. Speed was measured by radar for three weeks before and four weeks after the installation of road lights. In total, the speed of 273 780 vehicles was recorded. Furthermore, the concentration of drivers (in terms of attention to the traffic environment or road user alertness) was measured by self-reporting behaviour (questionnaire) and video registration of the lateral position of the vehicles. Increased lane drifting (i.e. sideways movements within a driving lane) is assumed to be a proxy measure for decreased driver vigilance or concentration.

The results of the data analysis of the Norwegian study (Assum et al., 1999) show that the car drivers compensate for road lighting both in terms of speed, and in terms of concentration. Following the installation of road lighting, mean driving speed increased both on straight road sections and in curves. The study also found that road users reported that they were somewhat less alert when driving on lit roads than when driving on unlit roads. Using lane drifting as an additional measure for road user concentration, it

[30] Behavioural and speed data for the same road section during daylight hours as well as data for darkness hours for an adjacent section of the same road without road lighting were used as controls (Assum et al., 1999).

was found that the amplitude of steering manoeuvres to correct lane drifting increased once road lighting was installed. This study supports the conclusion that road lighting is associated with road user behavioural adaptation, which partly offsets the engineering effect of the measure[31]. The technological effect from road lighting on safety is, nevertheless, far stronger than the incentive worsening effect.

### *3.3.2 Technical standards of roads*

The research study of Risa (2001), reported in section 3.1.3 (Mandatory Seat Belt Legislation), also incorporated a test of possible adverse incentive effects of technical road standards. In the accident risk models per particular group of road users, characteristics of technical standards of roads are captured by three different variables: (1) the share of hard surface roads, (2) the share of roads wider than seven meters, and (3) kilometres of physically separated paths for pedestrians and bicyclists per 1000 inhabitants.

The results imply the presence of compensating behaviour among road users (Risa, 2001). The indicator 'share of hard surface roads' yields positive and significant coefficients for both the risk accident model of injured automobile drivers and the risk accident model of injured moped drivers, outside densely populated areas. These results indicate that hard surface roads lead to behavioural compensation, resulting in more car and moped driver injuries. Concerning injury risk of pedestrians and bicyclists outside densely populated areas, the road width has a positive effect on injuries. In other words, wider roads induces risk compensation as a result of which the safety of vulnerable road users is endangered. Finally, inside densely populated areas, the share of kilometres of physically separated paths for pedestrians and bicyclists per 1000 inhabitants is associated with increasing car and moped driver injury risks. This implies that this road safety measure, intended to protect vulnerable road users, is accompanied with more injuries to the other road users.

[31] The researchers concluded that compensation is thus not sufficient to make road lighting ineffective as a road accident countermeasure (Assum et al., 1999).

### 3.3.3 Marked pedestrian crosswalks

Providing marked crosswalks has traditionally been one measure used in an attempt to facilitate crossings. They are commonly used at locations without traffic lights (uncontrolled locations). The purpose of marking crosswalks is to inform road users that the crosswalk should be a safe zone for pedestrians and to alert motorists to areas where pedestrians may be encountered (Zegeer et al., 2002). However, several research studies suggest that marked crosswalks might not always be safe for pedestrians. Researchers indicate that a marked crosswalk induces "a false sense of security" to vulnerable road users. They tend to feel safer crossing in a crosswalk and many assume that drivers will be able to see the crosswalk markings equally as well as pedestrians, making it safer to cross between the lines (MI, 2004)

Herms (1972, in Evans, 1991) investigated the effect on pedestrian safety of painted pedestrian crosswalks in San Diego, California. During a five-year period, he observed pedestrian injuries at 400 marked (or painted) and 400 unmarked crosswalks (uncontrolled intersections[32]). Relative to the numbers of pedestrians using the crosswalks, approximately twice as many pedestrians were struck in the marked crosswalks as in the unmarked crosswalks. According to Evans (1991), this large-scale, 'well-executed' study provides clear evidence of a case in which a safety improvement led to a dramatic reduction in safety. It appears that the painted crosswalk induced a sense of security in the pedestrians that was not justified by any increase in caution on the part of the drivers approaching it.

Jones and Tomcheck (2000) investigated the pedestrian accident rate at 104 intersections throughout the city of Los Angeles where marked crosswalks had been removed due to street resurfacing from February 1982 through December 1991. They observed an overall reduction of pedestrian accidents of 61,2 percent. Based on Dietz' curve of significance testing, this decline in pedestrian accidents after the removal of marked crosswalks is statistically significant and not due to random chance.

While the previous crosswalk studies have analyzed the overall safety effects of marked crosswalks, Zeeger et al. (2002) investigated the effects of these crosswalks for various

[32] Crosswalks at uncontrolled intersections are locations with no traffic signal or stop sign on the approach (Zegeer et al., 2002).

numbers of lanes, traffic volumes, or other roadway features. As hypothesized by the researchers, crosswalks should not be expected to be equally effective or appropriate under all roadway conditions. The purpose of this study was to determine whether marked crosswalks at uncontrolled locations are safer than unmarked crosswalks under various traffic and roadway conditions. A total of 1000 marked crosswalk sites and 1000 matched unmarked crossing sites (control group) in 30 cities across the United States were selected at random and data were collected during the 1994-1998 period. Poisson modelling and negative binomial regression were used in the analysis of the data. After controlling for other factors (e.g. pedestrian volume, traffic volume), the results revealed that on two-lane roads, there were no significant differences in pedestrian crashes for marked versus unmarked crosswalk sites. However, on multi-lane roads with traffic volumes greater than 10.000 vehicles a day, the pedestrian crash rate for marked crosswalks became increasingly worse as vehicle volume increased. The crash rate at unmarked crossings increased only slightly as traffic volume increased. There was also evidence of more fatal and seriously injured pedestrian crashes at marked crosswalks compared to unmarked crosswalks. The greatest difference in pedestrian crash types between marked and unmarked crosswalks involved 'multiple-threat' crashes[33]. One of the possible explanations of this difference could be that pedestrians, crossing in a marked crosswalk, may be less likely to look for another vehicle, once a first vehicle has stopped. In other words, the marking of crosswalks could cause more dangerous behaviour of vulnerable road users.

Finally, Koepsell et al. (2002) compared intersections where motor vehicles had collided with pedestrians aged 65 years or older with intersections of similar traffic density, speed limits, and numbers of lanes where collisions of older pedestrian and motor vehicles had not occurred, by the presence or absence of marked crosswalks. Over a five-year period, 846 crosswalks in six cities in Washington and California were studied. The researchers found that the risk of collisions was similar at intersections with or without marked crosswalks if the intersections were controlled by stop signs or signals. However, at intersections without stop signs or signals and after controlling for pedestrian and motor vehicle traffic density, pedestrians were three times as likely to be struck by motor vehicles in marked crosswalks as in unmarked crosswalks.

[33] A multiple-threat crash involves a driver stopping in one lane of a multi-lane road to permit pedestrians to cross, and an oncoming vehicle (in the same direction) strikes the pedestrian who is crossing in front of the stopped vehicle. This crash type involves both the pedestrian and driver failing to see each other in time in order to avoid the collision (Zegeer et al. 2002).

### 3.3.4 Flashing green traffic signal phase

Another measure, inducing risk compensation behaviour among motor vehicle drivers, concerns the use of a 'flashing green' signal at traffic lights. Before the traffic light turns to amber, road users are warned with a flickering green light. The purpose of this measure is to provide drivers with information to improve their stop or go decisions (Sagberg et al., 1996). It has been hypothesised that this measure would reduce the probability that drivers are trapped in the so-called 'dilemma zone' (Evans, 1991).

Hakkert and Mahalel (1978, in Evans, 1991) examined the effect of this flashing-green phase of traffic signals in Israel on crash rates. Based on various before versus after comparisons, the researchers concluded that the installation of the blinking green phase led to an increase rather than the intended decrease in crashes. Apparently the flashing-green phase made some drivers increase their speed to enter the intersection before the change to amber. In a follow-up study, Klein et al. (1983, quoted in Evans, 1991) used a movie film technique to capture motor vehicle drivers' behaviour. It was found that the blinking green phase placed additional pressure on the driver and created greater opportunity for error. It stimulated early decision to proceed, which sometimes had to be changed to a decision to stop, hence precipitating increased numbers of rear-end crashes.

### 3.3.5 Visibility at railway crossings

A railway crossing that has limited visibility, due to dense vegetation obscuring the view of the track and any approaching train, should be associated with a greater incidence of accidents because of the greater hazard associated with the obstruction of lateral visibility (Reinhardt-Rutland, 2001). However, evidence that restricted lateral visibility at railways is hazardous has not been forthcoming in spite of its apparent plausibility (Schoppert and Hoyt, 1968, quoted in Ward and Wilde, 1996).

Based on the tenets of the Risk Homeostasis theory, Ward and Wilde (1996) offer an explanation for the apparent disassociation between accident risk and lateral sightline visibility. It is proposed that, in case of limited visibility, motor vehicle drivers realise that their view of the track is restricted, and thus engage in compensatory modification of their approach behaviour. They will reduce their approaching speed in order to decrease stopping distance and to avail themselves of more time of visual search. In line with the risk homeostasis theory, road users are expected to realise an approximately constant safety margin (i.e. probability of an accident) and therefore the approach behaviour is modified to sustain a degree of perceived situational risk (Ward and Wilde, 1996).

Ward and Wilde (1996) investigated the enhancement of sight at unguarded railway crossings. They hypothesised that road users will perceive an increase in the approach safety of a railway crossing and that the approaching speed will increase commensurate with the perceived safety benefit of the sightline enhancement, resulting in no safety benefit. In their field study, Ward and Wilde (1996) made observations at an unprotected railway crossing before and after enhancement of existing lateral visibility. Parallel observations were made at an untreated site. By means of sonar units, vehicle speed was measured at several positions, while approaching the crossing. Observers recorded brake light activation and lateral head movements of the passing vehicles. In order to obtain perceptions of approach safety, local residents were surveyed.

The results obtained in this study are consistent with the above derived expectations (Ward and Wilde, 1996). In response to the sight distance improvement at the railway crossing, drivers consistently drove faster while approaching the railway crossing, resulting in no demonstrable net safety benefit. Furthermore, the majority of the surveyed residents reported a commensurate decrease in perceived risk (i.e. an increase in safety due to the enhanced visibility). In comparison, drivers at the control site, unaffected by any modification of visibility, demonstrated no comparable change in driving behaviour or any change in accepted safety margin.

## 3.4 Automobile insurance

### 3.4.1 Effects of compulsory insurance

According to economic theorists[34], the introduction of compulsory insurance is associated with moral hazard costs. The insurance protection tends to alter an individual's motive to prevent losses (Shavell, 1979). In case of automobile insurance, moral hazard is the tendency of reducing policyholders' incentives to take precautions and contract theorists predict that individuals will drive less carefully when insured. But whether this reduction in precautions, produced by automobile insurance, has a significant effect on traffic accidents, is an empirical matter, which has been little addressed by existing research. Only one research study is found (Cohen and Dehejia, 2004), which quantifies the moral hazard cost of compulsory automobile insurance[35].

Beginning in 1970, most American states adopted compulsory insurance requirements. According to Cohen and Dehejia (2004) moral hazard effects can be expected from uninsured motorist who purchase automobile insurance after the compulsory regulation. These motorists will drive less carefully when insured. Using an instrumental variable approach, in which the proportion of uninsured motorists is used to incorporate the regulation change, the effect on traffic fatalities during the 1970-1998 period is quantified. Furthermore the instrumental variable analysis controlled for a range of variables including automobile registration per capita, proportion of trucks among registered vehicles, the black fraction of the population, proportion of youngsters aged 18-24 of the population, violent and property crimes, unemployment, and per capita real income. The results show that the estimated effect of uninsured motorists on fatalities is significant and negative. This means that decreasing the ratio of uninsured motorists, by means of the introduction of compulsory automobile insurance, leads to an increase in the number of traffic fatalities. The magnitude of this moral hazard effect is potentially

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[34] See for instance Arrow (1963), Pauly (1968), Spence and Zeckhauser (1971), Shavell (1979) for theoretical backgrounds.

[35] Gaudry (1992) also addressed the issue of moral hazard associated with the introduction of compulsory insurance. He analysed the various effects on road safety of the new automobile insurance regime, introduced in Quebec in 1978. Although he did found an increase in accidents, he was not able to assign the precise part of increase to this moral hazard effect. Nevertheless, he concluded that forcing drivers to be insured, reduces their care levels on the road.

large: a 2 percent increase in the number of fatalities for each percentage point decrease in the number of uninsured motorists[36].

### 3.4.2 Effects of no-fault insurance/liability regulation

In this section, an overview will be given of the empirical literature concerning the influence of liability regulation on driver behaviour. More specifically, the effect on traffic safety of the reduction in liability will be examined. In contrast with a tort system[37] of liability, no-fault insurance regulation restricts the liability for damages to others. According to economists (Landes, 1982), this permits potential injurers to shift some of the costs of their activity onto potential victims and may result in higher losses from accidents. No-fault insurance thus has the moral hazard cost of reducing drivers' incentives to take precautions against the insured loss. Consequently, it has been argued that motorists will drive less carefully under a no-fault system than under a tort system (Cohen and Dehejia, 2004).

Landes (1982) investigated the effect on traffic fatalities of removing or restricting liability for motor vehicle accident injuries in the United States. It was hypothesised that laws that restrict liability for injuries arising from automobile accidents, will lead to increased automobile accident rates, with more restrictive laws leading to greater increases. The effect of restricting liability was examined by comparing states that have introduced no-fault insurance (or a form of no-fault insurance) with the states that have not introduced no-fault insurance, during the 1967-1976 period[38]. The fatal accident rates across states were regressed on several independent variables, being: dummy variables representing the type of insurance plan in a state, demographical variables (such as age, race and sex), state population, state density, the proportion of insurance claims barred from tort recovery by state's tort threshold, and state medical expense tort thresholds. The results show that in states where a moderate restriction on tort suits was in place, between 2 to 5% more fatal accidents are estimated to have taken place as a result of adopting no-fault insurance. States with more restrictive no-fault laws

[36] According to Cohen and Dehejia (2004), the estimated moral hazard of compulsory insurance is presumably larger. The effect is partly offset by the behaviour of those drivers who chose to remain uninsured. They are induced to driver more carefully, since their status as uninsured drivers is illegal under compulsory insurance laws.

[37] In a tort liability system, drivers are liable for losses to others that result from their negligent behaviour. Such a system provides optimal incentives for care in driving and accident prevention (Cohen and Dehejia, 2004).

[38] In total, sixteen states enacted no-fault automobile insurance laws between 1971-1976 (Landes, 1982).

experienced as many as 10 to 15% more fatal accidents in comparison to the states which did not introduce no-fault insurance.

Subsequent empirical results of the impact of no-fault automobile insurance regimes in the American States have been mixed. Whereas Landes (1982) found a positive relationship between no-fault and fatality rates, the empirical findings of Kochanowski and Young (1985)[39] and Zador and Lund (1986)[40] are inconsistent with the theory of adverse incentives caused by no-fault automobile insurance. However, Cummins et al. (2001) suggested that this lack of empirical evidence resulted from the fact that none of the prior studies controlled for the potential endogeneity of no-fault laws. Furthermore, the researchers enlarged the sample period with several years (1968-1994) and their analysis included a more complete set of explanatory variables (i.e. alcohol consumption, annual snowfall, miles driven, real income per capita, share of population with bachelor's degree, average speed, share of youngsters, number of hospitals per square mile). To represent the automobile compensation regime, estimates of the proportion of automobile bodily injury claims ineligible for tort due to no-fault thresholds were utilised (in addition to the standard approach of using dummy variables). Based on full fixed-effects panel data models, Cummins et al. (2001) concluded that no-fault insurance regimes are likely to be associated with higher fatality rates. In the regression models, controlling for endogeneity of no-fault insurance, represented as a dummy, is estimated to increase fatal accident rates by 12,8 to 13,8 %. Using the claims ineligibility ratios, the effect of no-fault is about 7,2 to 7,5 %.

Cohen and Dehejia (2004) also investigated the effect of accident liability laws on driver behaviour and traffic fatalities in the United States. Unlike the previous research studies, they distinguished between the effect of the introduction of compulsory automobile insurance[41] and changes in liability regulation. They estimated cross-sectional and time-serial regression models, which controlled for car registration per person, the share of

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[39] Using cross-sectional data for the United States for the years 1975, 1976 and 1977, the researchers did not found a statistical significant effect of the introduction of no-fault insurance on traffic fatalities per vehicle miles (Kochanowski and Young, 1985).

[40] Zador and Lund (1986) criticized the statistical methodology adopted by Landes (1982) and used multiple regressions to determine the extent to which variation in the frequency of fatal crashes during 1967-1980 could be attributed to the enactment of no-fault laws. The effect of these laws on fatal crashes was found to be statistically significant only in one out of 14 multiple regressions. This one result, suggested that the states with no-fault laws of low relative stringency, enjoyed a slight but statistically significant decrease in fatal crashes. Overall, there was no evidence in support of the moral hazard theory induced by no-fault insurance.

[41] Beginning in 1970, most American States adopted compulsory automobile requirements. Over the same period, 16 states adopted no-fault automobile insurance, whereas the other states enacted a tort liability regime (Cohen and Dehejia, 2004). For the analysis of the effect of compulsory insurance, see section 3.3.1 supra.

registered trucks, the share of lacks, violent crime, property crime, unemployment rate, income and the share of youngsters. The obtained results provide strong evidence of the adverse incentive effects of no-fault regulation. The effect on traffic fatalities per 10 000 inhabitants is estimated to be of an order of 10 percent[42].

Empirical evidence of the adverse effects of no-fault automobile regulation is also found in Quebec, New Zealand and Australia. Gaudry (1992) and Devlin (1992 in Sheldon, 1996) both examined the impact of the switch to no-fault insurance in Quebec in 1978. With the use of DRAG[43]-models, Gaudry (1992) examines the effect of this insurance system on the number of accidents with property damage only, and in terms of the number of accidents with injuries and fatalities during the 1956-1982 period. After controlling for more than 40 explanatory variables, he reported a 9,12% increase in accidents with fatalities, a 24,04% increase in accidents with injuries and a 9,81% increase in accidents with property damage only in the year after the introduction of no-fault insurance.  Similar results were obtained by Devlin (1992). He estimated that fatal accidents increased by 9,62%, injuries by 10% and property damage by 5,33%. McEwin (1989, quoted in Liao and White, 2002) used data from New Zealand and the Australian states for 1970-1981 and found that the adoption of no-fault was associated with a 16% increase in the number of road fatalities per head of population.

[42] While Cohen and Dehejia (2004) found considerable negative effects of the introduction of no-fault regulation in the United States (10% increase in fatalities), they stress that no-fault insurance systems clearly have benefits too, such as a substantial reduction of administrative costs with respect to tort liability systems. For a detailed discussion of the pros and cons of no-fault versus tort liability insurance,  see **Schwartz (2000).**

[43] Demand for road use, Accident frequency, Accident Gravity (Gaudry and Lassarre, 2000).

### 3.4.3 *Incentive effects of insurance contracts*

This section presents some empirical findings of research studies, concerned with analyzing the links between the form of existing automobile insurance contracts and the observed behaviour of the policyholders. A standard prediction of contract theory is that policyholders, who face contracts entailing more comprehensive coverage, should exhibit a larger accident probability. This phenomenon is true under a classical moral hazard story (Arnott and Stiglitz, 1988). Under moral hazard, it is assumed that contracts induce the corresponding behaviour through their underlying incentive structure. Drivers will react to the incentive structure of a specific contract. In case of more complete coverage, policyholders are encouraged to take less care in driving, which may result in higher accident rates[44] (Chiappori and Salanié, 2003).

However, empirical results of moral hazard in automobile insurance contracts are rather scarce. Some researchers cast doubt on the existence of moral hazard induced by automobile insurance contracts. They argue that moral hazard may be an important issue in some insurance markets, but not in others (Chiappori and Salanié, 2000). And although moral hazard in automobile insurance is theoretically well founded, empirical investigation of this phenomenon just started in the early nineties. Thus, there is a great lack between theoretical concepts and empirical evidence[45] (Chiappori and Salanié, 2000). Furthermore, statistical testing of moral hazard raises some complex questions. One of these, is concerned with another well-know phenomenon, called 'adverse selection' (Rothschild and Stiglitz, 1976). Both moral hazard and adverse selection result in the same empirical observational relationship in case of the correlation between insurance coverage and accident claims: i.e. higher insurance coverage is associated with more accidents. However, with respect to moral hazard, adverse selection reflects an inverted causality. Under adverse selection, high risk agents, knowing they are more likely to have an accident, self-select by choosing contracts entailing a more comprehensive coverage. In a moral hazard context, agents first choose different contracts. Then, an agent facing better coverage (for exogenous reasons) and, therefore, having weaker incentives, will be less cautious and have more accidents (Abbring et al., 2003a).

[44] However, empirical application is complicated because the insurer only observes claims and not accidents. The empirical distribution of claims will in general be a truncation of that of accidents, since 'small' accidents are typically not declared. Moreover, the truncation is endogenous: It depends on the type of insurance contract and also on the individual characteristics of the insured (Chiappori, 2001).

[45] For a more detailed elaboration of this finding, see Chiappori and Salanié (2000).

### a. Empirical evidence in a static context: the conditional correlation approach

In a pure static data context (i.e. not recognising the dynamics of behavioural responses, induced by insurance contracts), moral hazard appears as a positive correlation between contract choice and the level of risk taking. However, as stated above, the same correlation is observed under the adverse selection story. The bulk of the empirical work on insurance contracts inquires into this correlation and thereby not explicitly distinguishing between moral hazard and adverse selection  This approach is often referred to as the conditional correlation approach (Chiappori and Salanié, 2000). This method regresses both individual's insurance claims and her coverage choices on all observables on insurance company files, and then recover if the error terms from the two regressions are correlated. If they are, this provides evidence for adverse selection or moral hazard, as it means that individuals who have more claims than predicted also buy more insurance (Israel, 2004).

The basic reference of the empirical literature, in this context, is provided by the work of Puelz and Snow (1994). Their empirical test of the theory is to verify, in each risk class, whether lower deductibles are associated higher accident probabilities. Using individual data from an automobile insurer in Georgia, they build a two-equation model: the first one is a pricing equation (included independent variables are: the age of the automobile, deductible choice, multi-risk contract, wealth dummy variables, sex and the age of the insured), and the second describes the individual's choice of deductible (with the following independent variables: sex, wealth dummy variables, age of the insured, the marginal price of coverage and a dummy variable, indicating the occurrence of a claim in a particular year). The results suggest the existence of a negative relationship between deductibles and accident probabilities, either in favour of the moral hazard or the adverse selection concept[46].

Chiappori and Salanié (2000) investigated the adverse selection/moral hazard hypothesis on French insurer' records of 20 716 young drivers. They tested the conditional[47] independence of the choice of better coverage and the occurrence of an accident. Two bivariate probit models were set up: one for the choice of coverage and one for the

[46] However, other research studies report several flaws in the Puelz-Snow approach. The allegations are mainly based on model misspecifications.  For a detailed discussion,  see for example Chiappori and Salanié (2000) or Dionne et al. (2001).

[47] 'Conditional' means conditional on all variables observed by the insurer.

occurrence of an accident. In total, 55 exogenous variables were included in both models, for example: sex, make of car, performance of the car, type of use, type of area, age of driver, profession of driver, age of car, region. The results of the analysis show a very small correlation between the pair of probits. The authors conclude that adverse selection/moral hazard seems to be at most a negligible phenomenon in the market for automobile insurance in France, at least for young drivers.

Utilizing data of 104 639 policyholders of an Israeli automobile insurance company, during the years 1995 to 1999, Cohen (2005) tried to find evidence of adverse selection/moral hazard in two different ways. First, he tested for a correlation between low deductibles and more accidents using ordinary least squares and poisson specifications. The number of claims exceeding the regular deductible were regressed on all the characteristics of the policyholder and the vehicle and on a dummy variable representing whether a regular or a low deductible was chosen. The results of this analysis show that the probability of having at least one accident was higher by 4% for low-deductible policyholders than for regular-deductible policyholders. The average number of claims exceeding the regular deductible was 0,26 for low-deductible policyholders and 0,19 for regular-deductible policyholders. Low-deductible policyholders have approximately 20% more such claims than regular-deductible policyholders. Second, Cohen (2005) used the bivariate probit to estimate the correlation between the error terms of two binary equations: one for the deductible choice and one for the occurrence of a claim. Both equations have all the policyholder's characteristics as the independent variables. The estimated correlation between the error terms of the two equations, is negative, statistically significant and equal to – 0,055. Thus, the hypothesis that the two equations are independent can be rejected and the existence of adverse selection/moral hazard can be assumed.

### b. The dynamics of contracts: moral hazard and experience rating

The conditional correlation approach, using static data, cannot disentangle adverse selection and moral hazard. However, from a normative point of view, the statistical separation of these two phenomena is crucial as different policy reactions should be in place (Chiappori and Salanié, 2003). To solve this problem, the natural response is to turn to dynamic data (panel data).

Adverse selection and moral hazard indeed induce different behavioural dynamics, which provides a new source of identification (Abbring et al., 2003b). In insurance contracts, regulated by experience rating schemes (Bonus Malus), each accident increases the marginal cost of (future) accidents. Under moral hazard, any accident thus increases prevention efforts and reduces accident probability. The conclusion is that for any given individual, moral hazard induces a negative contagion phenomenon: the occurrence of an accident in the past reduces accident probability in the future. In other words, everything equal, the accident probability, conditional on past experience, should decrease with the number of past accidents. In an adverse selection setting, on the contrary, any accident signals a risky driver and thus increases the perceived probability of future accidents[48].

Israel (2004) followed the approach developed in Abbring et al. (2003a) to distinguish between moral hazard and adverse selection in automobile insurance. He used a 10 year panel of more than 30 000 consumers from one U.S. automobile insurer in Illinois. The main result of the analysis is evidence for a small, but statistically significant, moral hazard effect. That is, there is evidence that, controlling for observable characteristics and allowing for general state dependence in claims and unobserved heterogeneity, claims are less frequent when they are more expensive.

Other work, which find evidence of a moral hazard effect in a dynamic setting, is done by Dionne et al. (2004). They use longitudinal data in the French automobile insurance market for the 1995-1997 period. Using a multivariate dynamic panel data model, they found evidence of moral hazard, distinguished from adverse selection. The results indicate that, under the isolated moral hazard effect, drivers faced with significant increases in their bonus-malus and premium, switch from all-risk coverage to third-party coverage only (partial insurance). Furthermore, these drivers, while improving their safe-

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[48] For a more thorough discussion of the appropriate statistical and econometric techniques in case of dynamic insurance data, see for example Abbring et al. (2003a & b).

driving efforts, significantly reduce their chances of having an accident in the next contract period.

# 4. CONCLUSION AND RECOMMENDATIONS

The aim of this literature review was to present the theoretical foundations and empirical applications of offsetting behaviour in the traffic safety setting.  As section 3 'Empirical applications' shows, there is a diversity of situations in which road users adapt their behaviour. It is stated that these individuals will react to changes in driving conditions in a compensatory fashion such that riskier behaviours result from perceptions that the environment has become safer. For policymakers, however, the key question is how much offsetting behaviour actually occurs. As Peltzman (1975) acknowledges, offsetting behaviour could be trivial or substantial. Indeed, the amount varies between road safety measures. Behavioural adaptation generally does not eliminate the safety gains from programmes, but tends to reduce the size of the expected effects. Furthermore, in evaluating whether individuals display compensating behaviour in response to safety interventions, not all persons subject to the intervention will necessarily display compensating behaviour, even if this hypothesis is correct.

Nevertheless, the behavioural adaptation theory challenges the foundations of injury prevention strategies. The principal idea is to ensure that human beings do not adapt their behaviour to a reduced risk level after the introduction of safety measures but, on the contrary, benefit from those measures. It holds that the only effective safety measures are those that alter the desired risk level of the drivers. Anything that merely modifies the environment or that regulates driver behaviour without affecting the target risk level, is useless.

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