Voluntary internalization of speeding externalities with vehicle insurance

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\textbf{A B S T R A C T}

High speed is an important determinant of accidents for speeders as well as for other motorists. This paper develops a framework for analyzing instruments that encourage drivers to internalize the full consequences of their behavior with respect to choice of speed using Pay-As-You-Speed (PAYS) insurance, possibly as an extension of Pay-As-You-Drive (PAYD) insurance. We demonstrate how the combination of a Pigovian taxation scheme and PAYS can be designed in a setting involving two principals (the state and an insurance company) that affect the incentives of commuters to choose between driving and other modes of transport and for those that use the car mode to drive carefully. While the government is assumed to maximize overall social efficiency and therefore wants to implement marginal cost pricing, insurance companies do actuarial pricing, i.e. average cost pricing within risk classes that are homogeneous to the degree that the insurers have information about actual behavior. PAYS insurance improves the insurance industry’s possibility to differentiate premiums according to behavior and therefore to target risk classes in a better way than today. Moreover, since our framework is designed to accomplish differentiation by self-selection, compulsory regulation is not necessary, although there may be reason for the government to facilitate the implementation of the new technology.

\section{Introduction}

Road accidents are estimated to kill over a million people worldwide each year; recent statistics say 34,000 in the US (2009) and 43,000 in the EU (various years). Speed is an important determinant of accidents since it affects both the number and the incidence of accidents. A recent assessment by the European Traffic Safety Council (ETSC, 2010) estimates that a reduction of average car speed by one kilometer/hour would reduce the number of fatalities in road accidents in the EU by 2200, i.e., by 5%.

To handle the externality in speed choice, most societies use a combination of regulations (speed limits), enforcements (fines), fuel taxes and insurance schemes with deductions and bonus-malus\textsuperscript{1} provisions. A common problem of all these instruments is their limited relationship with actual driving behavior, and the present paper provides a scheme that would increase the precision of the policy mechanisms in targeting dangerous behavior.

To be more precise, insurance is a means for reducing the financial consequences of road traffic accidents. But the premium design also has consequences for driver behavior. On the one hand, economic theory predicts that insurance for automobile accidents will give rise to moral hazard that leads to less precautionary behavior by motorists and therefore to more...
accidents (Shavell, 1979, 1982, 2000). Empirical studies that exploit various natural experiments created by changes of legislation in different states in the US and Canada have findings that are consistent with this prediction (Cohen and Dehejia, 2003; Cassidy et al., 2000). On the other hand, insurance companies have access to means for pricing based on differentiation across drivers that represent different risk classes that at least partly can compensate for this.

Recently, Edlin and Mandic, (2006, subsequently E&K-M) have suggested that traffic policy should exploit vehicle-insurance pricing as a means for reducing automobile accidents. In an empirical study they established substantial road accident externalities with respect to distance in the United States. They conclude that the failure to charge for accident externalities provides an incentive for too much driving and too many accidents. They speculate that “the most efficient way to address the accident externality would probably be to levy a large tax on insurance premiums” (Edlin and Mandic, 2006, p. 952). However, as there are serious doubts “that Americans will accept any policy that substantially raises the cost of driving”, they propose a “second-best compromise”, which is to require insurance companies to quote premiums by the mile instead of per car and year. This would increase the marginal cost of driving, while the overall cost could be left at a comparable level.

This idea goes back to Vickrey (1968) who suggested a partial solution to problems of unaffordable insurance, uninsured driving, premium unfairness and inefficiencies by proposing usage-based car insurance. In fact, several insurance companies have now adopted Vickrey’s idea in the form of Pay-As-You-Drive (PAYD) automobile insurance that relies on Information and Communication Technologies for measuring distance driven (Bordoff and Noel, 2008). This policy enables insurers to charge the vehicle owner per mile instead of a pre-set number of miles per year. PAYD is offered to motorists on an optional basis, i.e., they can also choose a conventional scheme.2

The E&K-M proposal can therefore be interpreted as to make PAYD compulsory. For several reasons, it is not clear that this would get the traffic system sufficiently close to internalization targets, at least in other countries than the US.

First, while insurance companies have some means to differentiate charges with respect to heterogeneity in risk among different drivers, these are far from perfect. Current insurance premiums are not just “surprisingly invariant to the amount a given individual drives” (E&K-M, pp. 952–953) but also incompletely sensitive to how he or she drives. To obtain a risk classification, the insurer uses observable and accessible information that is correlated with ex post risk (claims). These instruments often have limited relationship with actual driving behavior. Also since claims are infrequent it can take a long time for a good driver to signal his or her type in order to receive a more accurate premium. Further, and in contrast to the US, insurers in most European countries do not have access to information about whether the policyholders have committed traffic violations.3 This obstructs the pricing of risk since traffic violations are a strong signal of risky behavior. As a consequence, high and low risk drivers may currently be pooled in risk groups that are considered homogenous by the risk classification. In addition, the European Court of Justice recently decided that, from 21 December 2012, it will no longer be legal under EU law to charge women less for insurance than men. This is expected to substantially increase vehicle insurance premiums for young women, as young male drivers have much higher risks of car accidents than young female drivers.

Second, the same technology that is used for (mandatory or voluntary) PAYD insurance can provide information on risky driving behavior (i.e., speeding) that can be used to improve the congruity of risk classifications with actual risk.4 It offers an opportunity for the motorist to lower the insurance premium by driving safer.

Third, some issues are unclear on the relation between vehicle insurance premiums and the external cost of accidents. E&K-M focus on the part of the cost of accidents covered by vehicle insurance. As will be demonstrated in Section 4 below, the cost of accidents that lead to fatalities and serious injuries is however much larger than what is covered by vehicle insurance. Also, coverage varies between US states and between different countries. At least within the EU, which intends to apply “full social marginal cost pricing” of transportation (European Commission, 1995), pricing based on a minor part of the total cost of accidents is far off the official policy target. Another concern is that internalization (Pigovian pricing) is based on the concept of marginal cost while insurance premiums are determined by actuarial pricing, which is an average cost concept.

Fourth, implementing PAYD insurance on a mandatory basis would require costly regulation, monitoring, and enforcement. Monitoring must establish that in-vehicle equipment is working, which is likely to be perceived more intrusive than external monitoring, such as speed controls. This may therefore be a hard pill to swallow for political decision makers. Since voluntary PAYD already exists an alternative route would be to consider ways to support faster market penetration of such schemes.5 Given that such schemes are offered on a voluntary basis, they can be differentiated more freely, for instance with respect to speeding behavior.

To be sure, speeding penalties and any tax targeted on speeding would also include a degree of self-selection, for instance in so far that any driver chooses speed knowing that there is a risk of being caught speeding. The particular voluntariness of PAYS is, however, that the costs are only incurred by monitoring drivers who choose to enroll in this scheme.

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2 Another possibility is annual odometer audits. However that would probably be much more costly than electronic measurement of distance (Bordoff and Noel, 2008).

3 In some countries, for instance Sweden, insurance companies do not exchange information between each other on previous claims by existing or previous customers. Thereby, low-risk customers’ switching costs are raised.

4 On available technologies, see Bordoff and Noel (2008). Other indicators of risky driving (short headways, frequent changes of lane, red-light passes etc.) may be accessible with future technologies.

5 Bordoff and Noel (2008) discuss in the US context barriers related to legislation, patents and economic incentives and suggest policies to reduce these.
While previous literature on vehicle insurance as a traffic policy instrument focuses on distance driven and how to reduce this (Edlin, 2003; E&K-M, Litman, 2001, 2005; Greenberg, 2009; Parry, 2004, 2005), this paper therefore focuses on risky driving behavior (speeding). Pay-As-You-Speed (PAYS) insurance calculates the insurance premium according to whether drivers comply with going speed restrictions or not. It has been tested in vehicle-fleet trials in Sweden (Hultkrantz and Lindberg, 2011), Denmark (Agerholm et al., 2008; Harms et al. (2008), and in the Netherlands (Bolderdijk et al., 2011) and was found to have a substantial effect on drivers’ choices of speeding frequency.

PAYD and PAYS insurance make use of the same type of in-vehicle technology, possibly except for a display alerting the driver when speeding, and given that digital maps contain information on speed limits, the two mechanisms could be integrated. For analytical reasons, the present paper however fully focuses on PAYS only. Moreover, while most attention so far has been paid to in-vehicle electronic measurement of mileage and speeding, there are several other dimensions of vehicle usage that can be recorded by new technologies and that could be possibly used for differentiation of vehicle insurance premiums.\(^6\)

This paper also makes a distinction between four different types of effects that affect the distribution of accident costs: (1) Once a traveler changes from another mode of transport to using car, this generates an accident risk not only to him- or herself but also to other motorists. (2) If the driver speeds this is a fortiori so. (3) The insurance industry typically does not cover all social accident costs but – at least in much of Europe – taxpayers foot the bill for hospital care, sick leave etc. (4) Finally, insurance premiums may involve cross-subsidization between groups of motorists with different risk.

The purpose of this paper is to suggest a design of Pigou taxation in combination with PAYS insurance in order to internalize road accident externalities. The setting involves two principals (the state and an insurance company) that affect the economic incentives of motorists for driving and for driving carefully. While the state regulator is assumed to aim for overall social efficiency by implementing full marginal cost pricing, the insurance company makes use of actuarial pricing to cover its costs, i.e. average cost pricing within risk classes that it estimates to be homogenous. Since insurance companies have means for differentiation across risk classes that are not available to the government, the insurer can be an agent for the regulator’s traffic safety policy. Another specific feature of this setting, in contrast to conventional Pigovian taxation, is that differentiation can be accomplished by self selection. Therefore, compulsory regulation is not necessary.

In Section 3, we use a modal-mix model to analyze the accident externalities from car driving and from speeding. The risk of collisions is the source of a reciprocal externality within the group of motorists, as every driver is increasing the accident risk of all drivers by just being on the road, and even more so if he or she is speeding. The distribution of accident costs is also to some extent affected by cross-subsidization by fiscal means and through the vehicle-insurance (with categories of drivers with different accident risk). The model we use comprises commuters who have a choice between a car mode and a reference travel mode. Motorists may also choose to comply or not to comply with speed limits; hence the model has three modes distinguished by speed (and therefore also time to get to destination) as well as accident risk. With this model we show how the cost burden of automobile accidents is spread between non-motorists and motorists with different risk. Further, we use the model to show how the modal mix, i.e., the driving and speeding decisions, are affected by a change from conventional to PAYS insurance, and, with conventional insurance, by a tax on vehicle insurance premiums. We also briefly discuss how a voluntary PAYS insurance can be priced.

Following up on this, Section 4 is used to derive Pigovian price equations for a complete internalization of car accident externalities with two sets of instruments; first a conventional solution that combines two taxes, a tax on driving (vehicle usage) and a tax on speeding (speeding tickets), and second a solution with PAYS insurance and a tax on vehicle insurance. It is thus necessary to use two separate policy instruments since it is important not only to induce roads users to drive at legal speeds but also to strike an optimal balance between whether to use the car mode or not. Using these price equations a numerical example, calibrated on Swedish data, indicates that the standard Pigovian tax solution would require very high speeding charges, while PAYS insurance could come close to a full internalization without any substantial change of the level of vehicle taxation in comparison to the current situation.

Before this analysis, we discuss some general issues related to accident externalities, speed and vehicle insurance in Section 2. Finally, the paper is concluded in Section 5.

2. Road, speed, and vehicle insurance

Much of the economic literature dealing with traffic accident externalities has focused on distance travelled. Vickrey (1968) suggests that driving entails substantial accident externalities that tort law do not internalize. An additional driver not only increases his or her own accident risk as a result of entering the road, but also the risk for others. The riskiness could, however, be reduced by the number of vehicles in the system in so far as additional congestion forces drivers to drive slower. Edlin and Mandic (2006) estimate auto accident externalities by using insurance premiums and loss costs, and find that externalities appear to be substantial in traffic-dense US states and smaller in low-traffic states. They conclude that a correcting Pigou tax could raise $220 billion annually in the US. Lindberg (2001) estimates the external marginal accident cost

\(^6\) In fact, some such cases already exist. For instance, in the UK “telematics-based insurance” is offered for young drivers. An electronic box in the car measures how the vehicle is maneuvered (accelerations, sharp turns, etc.) and if at the end of the insurance period the indicators are all right a large part of the premium will be refunded.
for a car in Sweden to be €11 per thousand vehicle kilometers in non-urban road traffic and €28 per thousand vehicle kilometers in urban road traffic. Many European countries charge the drivers' insurance company for their medical and other costs. Lindberg suggests that the Swedish average insurance premium would rise by 80% if these costs were internalized in the insurance policy. If strict liability is also introduced for car users, requiring them to compensate unprotected victims for half the accident costs, the insurance premium would rise by an additional 50%.

On the role of speeding, the research community seems to agree that speeding contributes to the number and the outcome of accidents (see Aarts and van Schagen (2006) for a review). Nilsson (2004) argues that the relationship between speed and accidents can be represented by a set of power functions (the Power Model): A given increase in speed increases the risk of an accident with material damages only, doubles the risk of light injuries, triples the risk for severe injuries and quadruples the risk of lethal accidents. Elvik et al. (2004), evaluate the Power Model by reviewing a large number of studies, and conclude that the empirical results support the model's predictions.

It has also been demonstrated that the number of previous traffic (speed) violations is a good predictor of accident risk (Grebers (1990), Boyer et al. (1991), Stradling et al. (2000)). Internalization of speed-related externalities would therefore deal with much of the accident risk externalities at large. Some countries have adopted a point system to warn drivers who repeatedly commit traffic safety violations. After a certain number of violations within some time period, the driver loses his license. Bourgome and Picard (2006) demonstrate that such systems improve social welfare. Furthermore, in some countries insurance companies have access to information about violations, and this can be used in the risk classification and hence the premium pricing.

The information and communication technologies now bring new possibilities for usage-based insurance schemes. Such schemes may allow insurance companies both to reduce moral hazard and to achieve a better risk classification and thus reduce adverse selection. Studies of pay-as-you-drive policies suggest that it would induce reductions in distance driven of 10% or more (Edlin (2003) and Bordoff and Noel (2008)). This reduction yield benefits from fewer accidents at the same time as a majority of drivers are better off due to a lower insurance premium. Nonetheless, the insurance industry may not want to switch to a system with per-mile premiums since monitoring mileage is costly relative to the potential gains.

Hultkrantz and Lindberg (2011) conducted an economic experiment in a vehicle fleet trial studying the effects of a pay-as-you-speed policy. A random-split sample of drivers in Sweden paying a non-linear speeding penalty reduced time speeding by more than 10% over the speed limits by 64%, while drivers that got equal feedback on speeding behavior but did not pay a penalty reduced such speeding time by only 15%. Likewise, studies among young drivers in Denmark (Agerholm et al. (2008), Harns et al. (2008)) and in the Netherlands (Bolderdijk et al., 2011) showed a substantial effect of speed-alert equipment in combination with a speeding penalty, in comparison to a control with the in-vehicle device switched off and no economic incentive.

Parry and Small (2005) develop an analytical framework for the second-best optimal gasoline tax accounting for externalities and interactions with the tax system. Comparing the optimal tax for the US and UK they suggest that welfare gains could be made by swapping gasoline for mileage taxes. Parry (2005) compares welfare effects of PAYD-insurance, fuel taxation and a tax on vehicle miles travelled (VMT), and shows that a PAYD insurance policy results in larger welfare gains than increases in fuel taxes to internalize the externality. By converting some of the fixed costs of vehicle ownership into costs that vary with mileage, the policy provides incentives to reduce mileage and fuel demand. Unlike higher fuel taxes, the costs for the average vehicle owner do not increase. For a given reduction in fuel demand, PAYD reduces mileage related externalities far more than fuel taxes and slightly more than a VMT tax.

### 3. A modal choice analysis of driving and speeding incentives

This section presents the model used for analyzing incentives to use cars or not and also whether to respect the going speed limits. To this end, Section 3.1 spells out the model framework, and Section 3.2 analyzes effects on modal choice by PAYS insurance and vehicle insurance taxation.

#### 3.1. The modal choice model

To provide a framework with which to analyze alternative policies for affecting speeding, we extend previous modal-choice models used by Arnott and Yan (2000), Glazier and Niskanen (2000), Armelius (2004), Armelius and Hultkrantz (2006), and Kutzbach (2009). In the present setting, N daily commuters have a choice between the car mode and all other modes of transport. Every commuter has a specific distance to travel each day, which means that there is no need to make a distinction between vehicle and distance, i.e. vehicle ownership and vehicle use are two sides of the same coin.

However, motorists also have a choice between compliance with road speed limits ("slow car") and non-compliance ("fast car"). Thus, there are three modes distinguished by speed and by impact on car accidents. The fixed number of commuters is N with shares n₀ (no car), nₛ (slow car) and n₇ (fast car); thus n₀ + nₛ + n₇ = 1. These shares are marked on a unit line Fig. 1 that represents the value of time (z) distribution in the population, which is assumed to be uniform. For reasons explained below the three modal shares are separated by two critical levels of the value of time, z and z'.

related to risk exposure, i.e. that number of work hours,
over a period of time with slow and fast cars is
accidents within other modes or between the car mode and other modes are normalized to zero. The number of accidents 3.1.1. Car accidents

Assume that cars use lanes that are separated from other traffic so that there are no cross-modal accidents; alternatively, accidents within other modes or between the car mode and other modes are normalized to zero. The number of accidents over a period of time with slow and fast cars is \( G_s(n_s, n_f) \) and \( G_f(n_s, n_f) \), respectively, with \( G_x(0, n_f) = 0 \) and \( G_x(n_s, 0) = 0 \).

The average accident risk of the two categories, \( \Psi_s, \Psi_f \), respectively, \( \Psi_x \), are assumed to be higher for fast than for slow vehicles, i.e. \[ \frac{\partial \Psi_x}{\partial n_f} > \frac{\partial \Psi_s}{\partial n_f} \quad \text{and} \quad \frac{\partial \Psi_f}{\partial n_f} > \frac{\partial \Psi_s}{\partial n_f} \]. The average risk of all motorists is \( \Psi = \frac{G_s + G_f}{n_s + n_f} \).

Both accident functions are assumed to be non-negative in both arguments. Moreover, since colliding with a fast car is always worse than colliding with a slow car, it must be that \[ \frac{\partial G_s}{\partial n_f} > \frac{\partial G_f}{\partial n_f} > 0 \quad \text{and} \quad \frac{\partial G_s}{\partial n_s} > \frac{\partial G_f}{\partial n_s} > 0 \].

The marginal accident risk invoked by an additional driver in one category on car accidents is the sum of the marginal effects on accidents in both categories, i.e.
\[ \Phi_x = \frac{\partial G_x}{\partial n_f} + \frac{\partial G_x}{\partial n_s} \] and \( \Phi_f = \frac{\partial G_f}{\partial n_f} + \frac{\partial G_f}{\partial n_s} \), respectively. The marginal accident risk by a change from slow to fast car mode is hence \( \Phi_f - \Phi_s \), while the marginal accident risk by a change from the no-car mode to slow car is \( \Phi_s \). For comparison with average risk the average marginal risk of a motorist is defined as \[ \Phi = \frac{n_f \Phi_f + n_s \Phi_s}{n_s + n_f} \].

Finally, we assume the own category number of accidents to be convex in the own category share of commuters, thus \( \frac{\partial G_x}{\partial n_x} > 0, \ i = s, f \). This implies that the marginal accident risk of each category is larger than the average risk, i.e., \( \Phi_x > \Psi_s \) and \( \Phi_f > \Psi_f \). The nature of these assumptions is that there are two categories of road users who differ in so far as one’s behavior is more dangerous than the others, both on average and at the margin; see Fig. 2.

The total (ex post) cost of an accident comprises three components. The first is the material cost due to vehicle damage etc., \( c^1 \). Vehicle owners buy insurance to deal with the financial consequences of accidents. For this model it is assumed that the insurance company takes up the whole cost, i.e. the presence of deductibles is disregarded. A second cost concerns hospital care and production loss, \( c^2 \). While individuals pay parts of these costs it is assumed that the social insurance system – the government – pays the bill. Finally, motorists involved in an accident suffer more than these financial consequences. This is captured by \( c^3 \), the pain and grief costs borne by all motorists involved in a collision. Total costs for a particular accident (\( C \)) are therefore \( C = c^1 + c^2 + c^3 \) and (annual) total accident costs to society are \( C \cdot [G_s(n_s, n_f) + G_f(n_s, n_f)] \).

3.1.2. The commuter
All individuals get utility (\( u \)) from consumption (\( x \)) and leisure (\( l \)) and suffer from the risk of being involved in an accident (\( G_i u_i = u(x, l, G_i) \), \( i = 0, s, f \)). Note that a more complete treatment would require individuals to be indexed. To simplify the presentation, this is disregarded.

For tractability, the utility function is further specified as (1). The price of the consumption commodity is normalized to unity, \( z \) is a leisure preference parameter, i.e. the value of travel time savings, uniformly distributed\(^7\) over [0, 1]. With a fixed number of work hours, \( z \) will define which mode the commuter will use. It is furthermore assumed that the individual’s cost is related to risk exposure, i.e. that \( G_i = \frac{G_i(n_s, n_f)}{n_f} = \Psi_i \).

\(^7\) As will be seen, an uniform distribution makes the model easy to solve.
Individuals work a fixed number of hours every day and get labor income $y$, equal for all. The 24 h of a day are used for work, traveling and leisure. The fast driver has most leisure with $l_f = l + x_f$ while the slow driver has $l_s = l + x_s$ and the other commuters only $l_b = l$. Here, $x_t$ is thus the time saving by changing from the other mode to slow car while $\xi$ is the additional time saving from driving fast.

After a lump sum tax ($t$) is subtracted from the income ($y$), the rest is used for consumption of the numeraire good and for car travel expenditure. Not using the car mode is assumed to cost nothing (2a). Spending on car travel (2b) and (2c) includes operation cost ($w$) and an insurance premium ($p$) and the expected value of speeding tickets per period of time ($\xi$) for the fast drivers (2c). More specifically, $\xi = d(\kappa) + F$ where $d(\kappa)$ is the probability of being detected which depends on the costs ($\kappa$) spent on surveillance. $F$ is the fine which is capped since it is not a parameter that can be set freely but may be restricted by concerns outside transport policy considerations. Hence, beyond some ceiling $\xi$ it is not increased without the government incurring additional costs.

3.1.3. Insurance companies and the government

The vehicle insurance is provided by Bertrand-wise competing insurance companies that set actuarially fair premiums. Each company gives insurance to an equal distribution of the two types of motorists. Provision of insurance is assumed to have constant returns to scale. The insurance covers material damage cost and insurance companies cannot differentiate between slow and fast car drivers. The insurance premium ($p$) is therefore8

$$p(n_s, n_f) = \frac{[G_s(n_s, n_f) + G_f(n_s, n_f)]}{(n_s + n_f)} \cdot C^1 \equiv \Psi \cdot C^1$$

At this stage of the analysis this premium, which here will be called a conventional insurance premium (in contrast to a differentiated PAYS scheme) is not distinguished from a PAYD insurance, since we are assuming that all commuters travel equal distances. We will later discuss how the two schemes can be integrated.

Except for fines, the public budget receives revenue from a lump-sum tax. These revenues plus those from speeding fines have to cover costs for hospital care. The public budget constraint is thus

$$t + n_f \xi = [G_s(n_s, n_f) + G_f(n_s, n_f)] \cdot C^2$$

Note that this version of the model does not include a tax on driving or vehicle ownership.

3.1.4. Model summary

The model incorporates two externalities. First, a commuter who switches from other commuting modes to car will increase the number of accidents for all car drivers. Second, a driver who chooses to speed will not only increase the risk for himself but also for all other speeders as well as non-speeders. In addition, drivers will not fully pay their own economic costs, both since insurers are not able to distinguish between slow and fast vehicles, and since hospital costs and some other costs are shared by the whole community of tax payers, and not just by car users.

Although we have not specified how the effective (expected value of) speeding charge is determined we have observed that there may be restrictions on the level of this charge. We will therefore return to the issue of optimal incentives to reduce speeding in the face of these restrictions.

3.2. Effects on modal choice by PAYS insurance and vehicle insurance taxation

This section analyzes how vehicle-insurance schemes and taxes on car vehicle ownership can be used to internalize external accident costs. We first discuss how a PAYS insurance scheme can be designed and how it would affect driving and speeding frequency in our model (Section 3.2.1). Then a similar analysis is made of a vehicle insurance tax given that vehicle insurance is not able to tell speeders apart from non-speeders (Section 3.2.2).

3.2.1. PAYS insurance vs. conventional insurance

A point of departure for the model is that a minimum vehicle insurance is compulsory, meaning that the motorist is limited to choose between different schemes and insurance companies but may not skip the insurance altogether. Let one insurance company, Company A, offer a PAYS vehicle insurance scheme based on the use of a technical device that at no cost records whether a
vehicle is used by a slow or a fast driver. Given actuarially fair pricing, the following set of premiums would be on offer: A PAYS insurant that is found to be a slow driver would pay \( p_s = \Psi_s c^1 \), while a PAYS insurant that is found to be a fast driver would pay \( p_f = \Psi_f c^1 \). Finally, an insurant that wants to have conventional vehicle insurance could still be offered \( p = \Psi c^1 \).

This set of premiums would make a slow driver prefer PAYS. Fast drivers would prefer switching to any of the other insurance companies since these by assumption do not (yet) differentiate the two categories and therefore offer a lower premium for the conventional scheme. However, that would increase the share of high risk drivers insured by the other companies, and they would therefore have to increase their premiums accordingly. This would then make slow car drivers switch from these other companies to company A. In (Nash) equilibrium, the vehicle insurance market will be separated so that slow car drivers insure at company A, while fast drivers insure at the other companies. Alternatively, the other companies can also offer the PAYS scheme and will be thus able to retain the low risk group.

This analysis of effects from usage of a PAYS scheme is not complete, however, since the new scheme also affects behavior. Driving and speeding frequency is in our model represented by the modal mix. Given the model assumptions, this is uniquely determined by the two value-of-time switch points – \( z \) and \( \xi \) in Fig. 1 – on which commuters are indifferent between going by car or by an alternative mode and between the driving within speed limits or speeding, respectively. These two points are characterized by the following equations.

\[
(1 - n_k - n_f) \cdot \lambda_s = w + p_s
\]

\[
(1 - n_f) \cdot \lambda_f = \xi + p_f - p_c
\]

The left hand sides show the value of the time saved when going from a slower to a faster mode (i.e., from non-car to slow car and from slow car to fast car, respectively). Since the value of time is assumed to be uniformly distributed over the population of commuters, simple expressions are derived for the value of time at the two margin points. The right hand side of Eq. (5a) shows the cost of driving a slow car (operation cost and insurance premium) compared to the non-car mode, while the right hand side of Eq. (5b) also includes the additional cost from speeding, which is the expected value of speeding charges plus the increase of the cost of insurance.

The effects on driving and speeding choices among the population of commuters from a total switch from conventional insurance to PAYS insurance can be derived from these two equations. With conventional insurance, \( p_s = p_f = p = \Psi c^1 \). When all insurance companies apply PAYS insurance \( p_s = \Psi_s \) and \( p_f = \Psi_f \). Since from the assumptions made in Section 3.1, \( \Psi_f(n_i, n_f) > \Psi_s(n_i, n_f) > \Psi_s(n_i, n_f) \) for any pair \( (n_i, n_f) \), we get Proposition 1:

**Proposition 1.** A change from conventional vehicle insurance to PAYS insurance will increase the share of car drivers in the commuting population and reduce the share of fast cars.

Whether the total number of accidents will decrease or not will depend on whether the increase of accidents because of the increase of car drivers is larger or smaller than the reduction of accidents because of the reduction of speeders. The net of these two effects is not clear on a priori grounds. Also, for reasons to be analyzed below, the effect on social welfare is obscure since a change to PAYS by itself does not lead to full internalization of the total external accident cost. Although the effect on total number of accidents is ambiguous, the effect on the accident rate is favorable. Thus, each person is made safer except for those who decide to switch to the auto mode, who are nevertheless made better off.

The insurance industry would have two motives for introducing PAYS vehicle insurance. First, it increases the market since more commuters use cars, and second, the number of high risk drivers decreases. Although we do not explicitly model the objectives of insurance companies in this analysis, both features are likely to be regarded as beneficial to the industry as a whole. However, the total cost of accidents may increase or decrease. Also, from the point of view of a single company, any effects on the modal choice of its customers will affect not just the cost of accidents that it is covering, but also the costs covered by other insurance companies. As a consequence, there is an externality from its change of policy.

### 3.2.2. Motives for vehicle insurance taxation

We now introduce the possibility for the government to levy a proportional (ad valorem) tax on vehicle insurance at the tax rate \( \theta \). The total (gross) premium of a conventional vehicle insurance will then be \( p = \Psi c^1 (1 + \theta) \), tax revenue being \( \Psi c^1 \theta \) with corresponding changes of the PAYS premiums.

One motive for this tax would be to handle the fact that that the insurance industry charges for the average risk in each risk group – here the whole insured population – while the welfare maximizing objective is to internalize effects at the margin of the risk group(s). E&KM estimate auto accident externalities based on differences in insurance premiums between different states in the US. They thus focus on the part of the total cost that is covered by vehicle insurance, which here is denoted \( c^1 \). A vehicle insurance tax would then be set so as to make the insurance premium of a commuter choosing between going by car and an alternative mode equal to the marginal accident risk in terms of the first cost component. This implies the following tax equation that corrects for the risk externality:

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9 This abstracts from customer loyalty issues. In reality, insurance companies combine different kind of insurances and offer varying bundles of premium and coverage, which hence softens price competition between companies.

10 Given actuarial pricing they always make zero profits. Absent customer loyalty, and as premiums are quoted before contracting, competition is perfect.

11 Since commuting distance is fixed in our model the total car traffic work can only be affected by mode choice.
\[ \theta = \frac{\Phi}{\Psi} - 1 \]  

But Eq. (6) internalizes the externality only with respect to the part of the accident costs that is covered by the insurance industry. In contrast, the Swedish government imposed a 32% tax on the compulsory vehicle insurance in July 2007. This tax was intended as a temporary substitute for a system similar to the one in several other EU countries where the public sector bills vehicle insurance companies for medical care expenditure etc. caused by traffic accidents (“recess rights”), while the legislative work on launching such a system was being carried out.\(^{12}\) It was thus motivated by a “fiscal externality” (part of the cost of automobile accidents is borne by non-motorists through taxation). This motive for a vehicle insurance tax is additional to the Pigovian externality motive. If both motives are combined, and in the absence of PAYS insurance, a possible tax rate for correcting for the accident externality, considering all cost components could be set as in Eq. (7). For subsequent use, it should be noted that Eq. (6) implies \( p = c^1\Phi \) and that Eq. (7) implies \( p = c\Phi \)

\[ \theta = \frac{\Phi C}{p} - 1 \]  

However, a tax set as in Eq. (7) does not lead to the first best. This is so because without PAYS insurance, \( p_s = p_f = p \), and that is not affected by taxation of vehicle insurance. From Eq. (6b) this trivially gives Proposition 2.

**Proposition 2.** With conventional insurance, a vehicle insurance tax will not affect the number (share) of commuters that are speeding.

Furthermore, since \( \Phi > \Phi_s \), Proposition 3 follows:

**Proposition 3.** With conventional insurance, a vehicle insurance tax determined by Eq. (7) will reduce the number (share) of motorists beyond what is warranted by internalization of the total external cost of accidents.

In this section we have examined the incentives of tax and insurance on driving and speeding decisions and how they would be affected by either PAYS insurance or a vehicle insurance tax. In next section, we will see how these two instruments can be combined so as to achieve a first best socially efficient outcome.

4. Pigovian pricing of accident externalities without and with PAYS

Our analysis comprises two market decisions that a regulator would like to affect, i.e. commuters’ choice between car and other modes and motorists’ choice of whether or not to drive legally. Two instruments are then required to establish a first best solution. Section 4.1 describes two pairs of such instruments that, in principle, could be used for this end while Section 4.2 is used to establish the consequences of the two schemes in a numerical application.

4.1. Two first best schemes

4.1.1. Taxes and speeding penalty

In a standard Pigovian setting the regulator can use a tax on driving and a speeding penalty to internalize accident risk. The tax on driving could be a driving-distance dependent tax such as a km-tax or a fuel tax, or a vehicle-insurance tax with PAYD insurance. For simplicity we use a vehicle tax, \( \tau \), and the speeding penalty, \( \xi \), to represent these levies. Each is set equal to the non-internalized marginal cost of accidents from an additional driver and an additional speeder, respectively:

\[ \tau = C\Phi_s - p = c^1(\Phi_s - \Psi) + \left( c^2 + c^3 \right)\Phi_s \]  

\[ \xi = C(\Phi_f - \Phi_s) \]

4.1.2. Combination of PAYS and taxes

For reasons to be further addressed in the next section, the speeding penalty may not be an appropriate instrument to deal with speeders. PAYS insurance does, however, provide an instrument for identifying the two types. We therefore now assume that the insurance industry has introduced this option and assess how the government could use two other instruments for internalization purposes. To make a distinction from the above scenario, this is referred to as a vehicle tax (\( \tau \)) and a tax on vehicle insurance (\( \theta \)). A first best solution can then be derived from the following equation system:

\[ \tau + p_s = \tau + c^1\Psi_s(1 + \theta) = C\Phi_s \]  

\[ \tau + p_f = \tau + c^1\Psi_f(1 + \theta) = C\Phi_f \]

This gives the following first best tax formulas

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\(^{12}\) In fact, the government decided in 2009 not to enact such a legislation while the tax still remains. Most EU countries and US states have insurance premium taxes (IPT), but at lower rates. For instance the IPT rate on car insurance in the UK is currently 6%.
\[ \tau = C \Phi_s - p_s = C \Phi_f - p_f. \]  \tag{10a} \\
\[ \theta = \frac{C}{c^1} \frac{\Phi_f - \Phi_s}{\psi_f - \psi_s} - 1 \]  \tag{10b} 

Eq. (10a) implies that the vehicle tax, in the same way as in the standard Pigovian case in Eq. (8a), is used to provide correct incentives for a commuter’s decision on whether to drive or not. The tax on vehicle insurance in Eq. (10b) calibrates the incentives for a motorist’s decision between speeding and non-speeding. The rate of the latter tax therefore depends on the ratio of the increment of marginal risk to the increment of average risk, scaled by the proportion of total societal cost to costs covered by insurance.

Two features of this solution should be noted. First, as the vehicle tax internalizes the accident externality of a careful driver, neither more nor less, drivers at large will not be overly priced off the road. Second, speeding is fully internalized without speeding charges. This means that while there is a cost of installing and administrating PAYS insurance,\(^\text{13}\) resources could be saved by reducing the costs for external monitoring and sanctioning of speeding.

\( \tau \) in Eq. (10a) is a fixed tax since the present model is not constructed to account for variations in distance driven. Since risk exposure grows with distance – albeit not necessarily linearly – the preferred design would be to use a tax related to mileage. This is straightforward if a distance or fuel tax would be used, since then the cost would be related to the average distance or fuel use.

Our next proposition sums up the discussion in this section.

**Proposition 4.** There are two alternative internalization mechanisms that could be used to implement first best, one which combines traditional insurance with a vehicle tax and a speeding penalty and the other which uses a vehicle tax and a tax on insurance in combination with PAYS.

### 4.2. A numerical example: The case of Sweden

We will now illustrate the consequences of the alternative mechanisms derived in Section 4.1 using Swedish data. To this end, Table 1a summarizes accident costs of different injuries as established by the Swedish National Road Administration. These numbers suggest that monetary costs caused by road accidents in Sweden amount to 0.4% of GDP, while the full social cost including non-monetary costs of suffering is 1.8% compared to GDP. To calculate the cost of an average accident, these costs are weighted together using the respective relative number of accidents as weight. No data is available on the number of accidents with material damages only. The Road Administration has, however, estimated the average cost for this class of accidents to be close to SEK 100,000. It is assumed that the material damage paid for by insurers is the same in all accidents and coincides with the estimated cost of property-only damages. We can then calculate the \( c^k \) parameters, \( k = 1, 2, 3 \) presented in Table 1b.

Total passenger kilometers with different modes are used as our proxy for \( n \). Total passenger kilometers were 126.4 billion in 2005. The car mode accounts for 77% of total traffic (97 billion car kilometers),\(^\text{14}\) which would then correspond to \((n_s + n_f)N\) in the model. Communications with Road Administration officials indicate that an estimated 57% of drivers exceed the going speed limit,\(^\text{15}\) meaning that we assume \( N \times n_s = 42 \) and \( N \times n_f = 55 \) billion km.

Table 1a shows that 26,899 individuals were involved in road accidents this year. The common perception among experts is that most of these accidents have speed as a contributing factor. Even if an accident has other primary causes, lower speed would improve the chances of dealing with a dangerous situation and avoiding an accident. For the time being, we assume that speed, defined in this way, is a contributing factor in 70% of all accidents, meaning that \( G_s = 8070 \) and \( G_f = 18829 \). From this it follows that \( \psi_s = 1.93 \times 10^{-7} \) and \( \psi_f = 3.40 \times 10^{-7} \).

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\(^{13}\) However, if PAYS insurance is added on the top of PAYD insurance, the incremental cost is likely to be very low.


\(^{15}\) Detailed statistics for different road types in Sweden and other European countries is found in ETSC (2010).
Vehicle insurance premiums paid in Sweden amounted to 22.8 billion SEK (Försäkringsförbundet, 2011). This implies an average annual premium per vehicle of 4100 SEK/vehicle (455 Euro/vehicle). Since insurance coverage varies and not all vehicles are insured, we will present results below for two levels of the total annual accident cost borne by the vehicle owner: 4000 and 6000 SEK.

Finally, we need to make assumptions about the marginal risk. The evidence is limited, so we have calibrated the model using results for various US states from E&K-M and for Sweden from Lindberg (2001). Eq. (11) is used to estimate the marginal effects on accidents of the two categories of drivers; μ < 1 and the a-coefficients are shown in Table 2:

\[ Φ_i = μ(a_0 + a_µ Ψ_i), i = s, f \]  

E&K-M find that the accident externality – cf. Eq. (6) – is 50–100% relative to insurance premiums in three US states with medium traffic density (Maine, Kentucky and South Carolina), which we take as a point of departure also for Sweden. Based on Lindberg (2001), and using the costs shown in Tables 1a and 1b, the Swedish Transport Administration, STA (2011), estimates the value of car accident externalities to be 0.20 SEK/km. Calibrating, we find that μ = 0.6 corresponds to a relative accident externality at 51%, and a externality cost of 0.20–0.33 SEK/km at the two insurance premium levels. We will therefore present results for this value of μ.

With this data we can now compute the optimal tax rates, using Eqs. (8a), (8b), (10a), (10b), (11a) and (11b). The results are presented in Table 3. Before addressing the results it is, however, important to emphasise that the figures do not account for any behavioral adjustments generated by the taxes; references given above clearly indicate that the taxes do affect behavior.

The first two rows present results under a standard vehicle insurance scheme. It indicates that the marginal accident externality cost of a careful driver is 0.20–0.34 SEK/km and that the tax therefore should be at this level. The next row shows the optimal level of expected fines, which is equal to the marginal externality cost of speeding. This is estimated to be of the same magnitude, 0.25 SEK/km. According to STA (2011), the current total marginal externality cost of a petrol-fueled automobile in non-congested areas is 0.45 SEK/km, whereof 0.20 due to accidents and 0.25 due to emissions. At the same time, the current fuel tax on average internalizes 0.48 SEK/km, i.e., the degree of internalization is 1.07. Thus it seems that taxation of vehicle usage already, more or less, correspond to the optimal tax rate according to Eq. (8a).

This is not the case for speeding fines. According to ESTC (2010), the number of speeding tickets in Sweden in 2007 was 218,939. This corresponds to a 4% annual probability of ticket per vehicle for all vehicles and 7% for speeding vehicles. Assuming that the average speeding ticket is SEK 3000, the average speeding ticket cost of a speeding vehicle is then 0.014 SEK/km, which is less than 6% of the estimated optimal cost of speeding fines according to Table 3. Given this actual detection rate, the optimal speeding ticket would therefore have to be 18 times higher than the present, i.e., SEK 54,000. This is a third of the average annual disposalable income per Swedish resident in 2007, so a ticket of this size would clearly be a considered as a strong punishment.

Going to the entry for Eq. (10a) in Table 3, the optimal vehicle usage tax for the careful driver is 0.29 SEK/km, i.e., a little more than what is currently internalized through the fuel tax (0.48–0.25 = 0.23 SEK/km). On the next line, an optimal insurance tax ranges from 12–68%, depending on what assumption is made about the current accident cost borne by the vehicle owner. Thus, the current vehicle insurance tax in Sweden at 32% is within this span. This result of the numerical estimation is highlighted as an observation.

16 Accident costs are internalized (ex ante) in two ways, by insurance premiums, and by the expected value of deductibles and other costs not covered by insurance; so we have only information about the first of these two components. New cars are usually sold with a 3-year full insurance coverage (with some deductibles). For older cars owners have a choice between liability insurance and full coverage.

17 Without the μ-factor, a marginal effect would always at least be double the size of the average risk. This is true if all accidents are collisions between two cars and if driving behavior is unaffected by traffic volume. Since this is not so in the real world, we need to calibrate with this factor.

18 Tickets vary between SEK 1500-4000 for speeding less than 30 km/h above the speed limit.

19 However, since the tax base it the compulsory insurance premiums, the effective rate (i.e., the share of the tax to the total accident cost borne by a vehicle owner) is at the lower end of this range.
Observation. Due to external restrictions that cap the size of the speeding fine, it is not feasible to implement a first best policy with respect to safe driving using this instrument. PAYS in combination with a tax on the insurance premium would, however, implement an optimal policy.

5. Conclusions

Traffic policy is the government’s business while vehicle insurance is provided by insurance companies on market terms. It may be thought therefore that indirect control of car drivers via (differentiated) insurance premiums would be inferior to direct charges or taxes on drivers. This paper however suggests that PAYS can be handled to be a tool for using the insurance industry as an agent in the government’s traffic safety policy. This assertion is based on that the insurance industry has access to pricing options that are not available to the state:

(1) The voluntary nature of contractual agreements mitigates many problems that arise in a fiscal setting. Unlike tax authorities, insurers can thus offer consumers a menu of programs, enabling differentiation by self-selection and allowing alternatives to those who, for instance, dislike having their speed monitored.

(2) Insurance companies have access to information that can be used to price risky driving behavior, like records of previous claims that may not be available to fiscal authorities.

(3) Insurance companies have superior experience in identifying risk and implementing policies that favor good and penalize bad behavior.

The introduction asserted that in spite of these possibilities current technologies used by insurers are surprisingly invariant to actual driver behavior, which would indicate that the industry in reality has no advantage over the government in this respect. It is, however, reasonable to expect that today’s degree of differentiation is endogenous to the difference in risk and the costs for using more sophisticated means to charge policy holders. Novel techniques may well change this fact.

Previous literature on how taxation can be exploited for traffic safety policy purposes has focused on the improved possibilities for measuring distance driven, while we highlight monitoring of speeding. However, there is a range of other risk factors that could be supervised, some of which are already used by the insurance industry. For instance, one Swedish insurance provider charges a lower premium to vehicles that have an alco-lock installed to make it impossible to use the vehicle for an intoxicated driver.

Incentives based on on-board monitoring of individual drivers do not necessarily involve “Big Brother” privacy problems. Such problems would only occur if detailed vehicle positioning information is stored in a central computer, not just used for instantaneous measurement. What actually is required for incentive purposes is summary statistics at an aggregate level. For instance, a monthly or annual summary of the number of minutes the vehicle has been used for driving at a speed exceeding speed limits by a certain percentage, much in the same way as mobile phone bills are designed, is sufficient (Troncosco et al., 2007). Besides, a basic idea in this paper is that PAYS is offered as an additional contract in the compulsory vehicle insurance, making it possible for drivers to self-select with due account of their preferences for being monitored (and their preferences for speeding).

Our numerical estimates indicate that although the external costs of driving cars in non-congested areas in Sweden seem to be internalized by the current fuel tax, the external cost of speeding is only to a very small extent internalized by the expected cost of speeding tickets. It is furthermore established that with PAYS insurance a full internalization is feasible without any major changes of current tax rates on usage (fuel) tax and vehicle insurance. Of course, this result should be taken with a grain of salt as we have made a very coarse calculation. Also, we have not taken into account that there will be, as intended, behavioral adjustments. In particular, speeding is likely to decrease.

The good news is, however, that with PAYS insurance taxes can be designed so as to reduce the role of speeding tickets.\textsuperscript{20} Hence, the system would mean that speeders – who by assumption are not inclined to install the equipment – could continue their behavior and get away with it by paying a higher insurance premium. While this could be interpreted as a mechanism for paying for the right to speed, the main difference compared with today would be that people speed without having to pay (fully) for it.

\textsuperscript{20} As long as the PAYS insurance is voluntary some need for external speed monitoring remains because otherwise those who stick with conventional insurance will speed even more than presently.
A caveat is, however, that vehicle insurance is assumed to be compulsory and that all drivers actually pay. However, even
when vehicle insurance only has to cover material vehicle damages, and even in a country with such law-obeying motorists
as in Sweden, a fraction of the cars are driven without any insurance (and/or without paying vehicle taxes). That proportion
would likely increase if insurance fees were raised. The use of vehicle insurance to internalize the full social cost of accidents
would thus in a way transform the traffic surveillance problem from detection of speeding to detection of non-insurance. As
monitoring of non-insured vehicles is as a rule considerably more easy than monitoring of speeding we regard this as a mi-
nor objection.

Also, it should be kept in mind that real-world implementation involves many considerations that are not captured by our
simplistic model. For instance, car “speeding” is here treated as a zero-one binary variable, while the external cost depends
on the actual speed, that is, a continuous variable, and also on when and where the car is driven. In fact, PAYS insurance
schemes can be elaborated in various dimensions, for instance by implying “speeding penalties” that are proportional or pro-
gressive with respect to how much speed limits are exceeded. On the other hand, there are limits to the cognitive load that
can be put on car drivers, so there may be good reasons to keep insurance schemes simple.

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