Voluntary Internalization of Speeding Externalities

Lars Hultkrantz
Swedish Business School, Örebro University

Jan-Eric Nilsson
Centre of Transport Studies; VTI

Sara Arvidsson
Centre of Transport Studies; VTI

March 15, 2011

Abstract: High speed is an important determinant of accidents. This paper develops a framework for analyzing instruments which encourage drivers to respect the going speed limits. It shows how pay-as-you-speed (PAYS) insurance, possibly as an extension of pay-as-you-drive (PAYD) insurance, may be used to target speeding externalities. We demonstrate how a Pigovian pricing scheme can be implemented in a setting that involves two principals (the state and an insurance company) that regulate the economic incentives of motorists for driving and for driving carefully. While the state regulator is assumed to aim for overall social efficiency and therefore wants to implement full marginal cost pricing, insurance companies do actuarial pricing, i.e. average cost pricing within homogeneous risk classes. Insurance companies, however, have means for differentiation across risk classes that are not available to the state. Also, since differentiation can be accomplished by self selection, compulsory regulation is not necessary.

1 We are grateful for comments from Björn Carlén, Svante Mandell, Kenneth Small, two anonymous reviewers and seminar participants at Örebro University, VTI, Andrew Young School of Policy Studies and the Kuhmo-Nectar conference 2010.

2 Corresponding author: Lars Hultkrantz, Örebro University, 701 82, Örebro, Sweden. Telephone: + 46 19 30 14 16. E-mail: lars.hultkrantz@oru.se
1. Introduction

Internalization of external costs of transport has been high on the transport policy agenda for a long time. In addition, economists and increasingly also policy-makers acknowledge that there is a need for more differentiated prices or other instruments to efficiently handle these externalities. Hitherto, internalization has focused on surcharges on fuel, i.e. on driven distance (Edlin 2003, Parry 2005). While the fuel tax is a precision instrument to make motorists internalize the external cost of carbon dioxide emissions, it does not differentiate between driving in densely and sparsely populated areas and is unsuitable for targeting congestion externalities.

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). The external dimension of accident risk is another cost that is not necessarily linear in fuel and distance. In particular, speed is an important determinant of accidents since it affects the number and outcome 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 2,200, i.e., by five percent. 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\(^3\) provisions. A common problem of all these instruments is their limited relationship with actual driving behavior.

Boyer and Dionne (1983) pointed to the benefits of providing direct incentives to drivers for speed compliance but this was not further explored because ‘it is usually either very difficult or extremely costly to observe self-protecting activities of a particular individual’. Technological achievements such as radar and Automatic Traffic Control (ATC) camera surveillance have partly changed this situation. However, these means only facilitate speed monitoring at specific locations or specific occasions, are balanced by other technological developments such as ATC camera alerts and involve substantial cost, not least for enforcing and administrating sanctions. A further technological step is therefore provided by Informa-

\(^3\) In insurance, a bonus-malus system is a system that adjusts the premium paid by a customer according to his individual claim history.
tion and Communication Technology (ICT) to allow continuous in-vehicle monitoring of speed by use of the Global Positioning System (GPS) and digital maps.

Early on, Vickrey (1968) suggested a partial solution to problems of unaffordable insurance, uninsured driving, premium unfairness and inefficiencies by proposing usage-based car insurance. Several insurance companies have now adopted Vickrey’s idea in the form of Pay-As-You-Drive (PAYD) automobile insurance that relies on ICT devices 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.

In the US, Edlin (2003), Edlin and Karaca-Mandic (2006), and Bordoff and Noel (2008) recently have brought new attention to Vickrey’s suggestion. Impetus was provided by an empirical study of accident externalities with respect to driving by Edlin and Karaca-Mandic (2006). These were found to be substantial, and the authors conclude that the failure to charge for high accident externalities provides the incentive for too much driving and too many accidents in the US. Considering correcting policies, they speculate that “the most efficient way to address the accident externality would probably be to levy a large tax on insurance premiums”. 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 per year, hence to use compulsory PAYD schemes⁴. This would increase the marginal cost of driving, while the overall cost could be left at a comparable level.

However, it is not clear that this solution 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” (Edlin and Karaca-Madlin 2006, pp. 952-3) but also incompletely sensitive to bow 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 available

---

⁴ Another possibility is annual odometer audits. However that would probably be much more costly than electronic measurement of distance (Bordoff and Noel 2008)
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, in most European countries the insurers do not, in contrast to in the U.S., have access to whether the policyholders commit traffic violations, which obstruct the pricing of risky behavior. Therefore, high and low risk drivers currently may be pooled in risk groups that are considered homogenous by the risk classification. Finally, 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, precisely 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.\(^5\) 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. Edlin and Karaca-Mandic (2006) focus on the part of the cost of accidents covered by vehicle insurance. However, the cost of accidents that lead to fatalities and serious injuries is much larger than what is covered by vehicle-insurance\(^6\). 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.

Finally, implementing PAYD insurance on a mandatory basis as suggested by Edlin and Karaca-Mandic (2006) requires costly regulation, monitoring, and enforcement. Monitoring must establish that in-vehicle equipment is working, which is likely to be per-

\(^{5}\) 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.

\(^{6}\) See Section 5 in this paper.
ceived more intrusive than external monitoring, such as speed monitoring. This may therefore be a hard pill to swallow for political decision makers. As voluntary PAYD already exists an alternative route would be to consider ways to support faster market penetration of such schemes. Given that such schemes are offered on a voluntary basis, they can be differentiated more freely, for instance with respect to speeding behavior.

This paper is devoted to the internalization of external accident costs, in particular risks related to speeding, through the use of ICT in combination with institutional adjustments of the way in which this particular market works. While the previous literature focuses on distance driven and how to reduce this (Edlin 2003, Edlin and Karaca-Mandic 2006, Litman 2001 and 2005, Greenberg 2009, Parry 2004 and 2005), this paper focuses on reducing 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, 2012) and in Denmark (Agerholm et al. 2008) and found to have a substantial effect on drivers’ choices of speeding frequency.

Using a modal choice type of model, the purpose of this paper is to evaluate the benefits of the introduction of PAYS in combination with institutional changes of the responsibility for society’s accident costs. We demonstrate how a Pigovian pricing scheme can be implemented in a setting that involves two principals (the state and an insurance company) that regulate the economic incentives of motorists for driving and for driving carefully. While the state regulator is assumed to aim for overall social efficiency and therefore wants to implement full marginal cost pricing, insurance companies do actuarial pricing, i.e. average cost pricing within homogeneous risk classes. Insurance companies, however, have means for differentiation across risk classes that are not available to the state. 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.

The model we use comprises a given number of commuters between an Origin and a Destination, 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 com-

---

7 Bordoff and Noel (2008) discuss in the U.S. context barriers related to legislation, patents and economic incentives and suggest policies to reduce these.
prises three modes distinguished by speed (and therefore also time to get to destination) as well as accident risk. The analysis moreover deals with all social costs for traffic accidents, namely material damages, production loss and hospital care as well as individual suffering (non-monetary cost of pain and grief), each borne by different economic subjects.

The model is developed in section 3. Section 4 analyzes the effects on driving and speeding by economic incentives that are governed by different vehicle insurance schemes and taxation of vehicles and driving. First, we discuss what a PAYS premium scheme would be and then how a change from a conventional insurance scheme to PAYs would affect total car usage and speeding frequency. Then we study motives and design for a vehicle-insurance tax and how it would affect car usage and speeding frequency under a conventional vehicle insurance scheme. Finally, we compare three different ways to implement a first best full internalization of speeding externalities; a standard Pigovian tax solution based on vehicle tax and speeding charges, a social marginal cost PAYS insurance where insurance companies take the role of state regulators, and a solution with PAYS insurance based on actuarially fair prices combined with a vehicle tax and a vehicle insurance tax. Based on Swedish data, section 5 provides a numerical example which suggests that full internalization requires such a vehicle insurance tax because the non-monetary cost of human suffering is much larger than the cost of hospital care and other such monetary costs. We also show that the standard Pigovian tax solution would require very high speeding charges.

2. Related literature

Much of the 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 Karaca-Mandic (2003) 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 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 percent 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 percent.

Based on Vickrey’s (1968) central insights, studies of pay-as-you-drive (PAYD) policies suggest that it would induce reductions in distance driven of 10 percent 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.

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.

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). Internalisation 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 licence. 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 research community thus seems to agree that speeding contributes to the number and the outcome of accidents (see Aarts and van Schagen (2005) 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.

### 3. The modal choice model

To provide a framework with which to analyze alternative policies for affecting vehicle speed, we recycle previous modal-choice models used by Arnott and Yan (2000), Glazer and Niskanen (2000), Small and Yan (2001), 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 \(n_0\) (no car), \(n_s\) (slow car) and \(n_f\) (fast car); thus \(n_0 + n_s + n_f = 1\). These shares are marked on a unit line Figure 1 that represents the value of time (\(z\)) distribution in the population, which is as-
assumed to be uniform. For reasons explained below the three modal shares are separated by two critical levels of the value of time.

![Graph showing modal shares on a uniform value-of-time distribution](image)

**Figure 1.** Modal shares on a uniform value-of-time distribution. Two split points—\( \hat{z} \) and \( \bar{z} \)—divide commuters into three modes.

### 3.1 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 \( G_s(0, n_f) = 0 \) and \( G_f(n_s, 0) = 0 \).

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

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 \( \frac{\partial G_f}{\partial n_f} > \frac{\partial G_f}{\partial n_s} > 0 \) and \( \frac{\partial G_s}{\partial n_f} > \frac{\partial G_s}{\partial n_s} > 0 \).

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.
\[ \Phi_s = \frac{\partial G_s(.)}{\partial n_s} + \frac{\partial G_f(.)}{\partial n_s} \quad \text{and} \quad \Phi_f = \frac{\partial G_s(.)}{\partial n_f} + \frac{\partial G_f(.)}{\partial n_f}, \]
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 we define the average marginal risk of a motorist as \( \Phi = \frac{n_s \Phi_s + n_f \Phi_f}{n_s + n_f} \).

Finally, we assume the own category number of accidents to be convex in the own category share of commuters, thus \( \frac{\partial^2 G_i(.)}{\partial n_i^2} > 0, i = s, f \). This implies that the marginal accident risk of each category is larger than the average risk, i.e., \( \Phi_s > \Psi_s \) 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 Figure 2.

![Figure 2: The number of accidents with slow and fast cars and properties of average (ratio of dotted lines) and marginal (tangent to the G_i functions) risks.](image)

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 $C : [G_i(n_i, n_f) + G_f(n_s, n_f)]$.

### 3.2 The commuter

All individuals get utility ($u$) from consumption ($x$) and leisure ($l$) and suffer from the risk of being involved in an accident ($G_i$; cf. eq. 1). 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 (2). 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\(^8\) 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 $G_i = G_i(n_i, n_f)/n_i = \Psi_i$

\begin{align}
  u_i &= u[x_i, l_i, G_i] \quad \text{for } i = 0, s, f \quad (1) \\
  u_i &= x_i + z_i \cdot l_i - c^3 \cdot \Psi_i \quad (2)
\end{align}

Individuals work a fixed number of hours every day and get labor income $y$, equal for all. The 24 hours of a day are used for work, travelling and leisure. The fast driver has most leisure with $l_j = l + \lambda_i + \lambda_f$ while the slow driver has $l_s = l + \lambda_s$ and the other commuters only $l_0 = l$. $\lambda_s$ is thus the time saving by changing from the other mode to slow car while $\lambda_i$ 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 (3a). Spending on car travel (3b and 3c) includes operation cost ($\nu$) and an insurance premium ($p$) and the expected value of speeding tickets per period of time ($\tilde{c}$) for the fast drivers (3c). More specifically, $\tilde{c} = d(\kappa) * \bar{F}$ where $d(\kappa)$ is the probability of being detected which depends on the costs ($\kappa$) spent on surveillance. $\bar{F}$ is the fine which is capped since it is not a parameter that can be set freely but is restricted by concerns outside transport policy considerations. Hence, beyond some ceiling $\bar{c}$ cannot be increased without the government incurring additional costs.

\[^8\text{As will be seen in section 4.3 an uniform distribution makes the model easy to solve.}\]
\[ y - t = x_0 \quad (3a) \]
\[ y - t - w - p = x_s \quad (3b) \]
\[ y - t - w - p - \xi = x_f \quad (3c) \]

3.3 Insurance companies and the government

The compulsory 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 therefore\(^9\)

\[
p(n_s, n_f) = \frac{[G_x(n_s, n_f) + G_y(n_s, n_f)]}{(n_s + n_f)N} \cdot c^1 \equiv \Psi \cdot c^1 \quad (4) \]

It should be observed that this premium, which here will be called a conventional insurance premium (in contrast to a differentiated PAYS scheme) in our model cannot be distinguished from a PAYD insurance, as we are assuming that all commuters travel equal distances. On the other hand, going from a conventional “lump-sum” premium to PAYS also makes it possible to offer PAYD insurance, as the technology and administrative system of PAYS in all practical aspects is equal to that of PAYD.

The public budget receives revenue from a lump-sum tax. These revenues have to cover costs for hospital care. The public budget constraint is thus

\[
t + n_f \xi = [G_x(n_s, n_f) + G_y(n_s, n_f)] \cdot c^2 \quad (5) \]

Note that this version of the model does not include a tax on driving or vehicle ownership. The consequence is that commuters who do not use cars also pay for hospital care and income loss through the social insurance system.

---

\(^9\) We assume a full coverage pooling premium. Alternatively, there may be separating equilibrium premiums designed to make high and low risk motorists self select. However, such a scheme would not give full coverage to both types. See Arvidsson (2011).
3.4 Summary

The model incorporates externalities in several dimensions. 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. And third, there is an externality on the cost side in so far as drivers will not pay for the full economic costs of their choices, both since insurers are not able to distinguish between slow and fast vehicles and also since hospital costs are shared by the whole community of tax payers, and not just by car users.

Further, although we have not specified how the effective (expected value of) speeding charge is determined we have observed that it cannot be set freely because of considerations that are exogenous to this model. Thus, although there is an economic incentive to reduce speeding, it may not be (in fact will here be assumed to not be) sufficient for full internalization of the accident externality from speeding.

4. Insurance schemes and tax instruments

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. Then a similar analysis is made of a vehicle insurance tax given that vehicle insurance does not differentiate speeders. Finally, we compare and discuss different combinations of insurance and tax schemes that may provide full internalization.

4.1 PAYS insurance vs. conventional insurance

Let one insurance company, Company A, have the possibility to offer a PAYS vehicle insurance scheme based on the use of a technical device that at no cost records whether the driver is a slow or a fast driver. Given actuarially fair pricing, PAYS insurees could be offered the following set of premiums: A PAYS insuree that is found to be a slow driver would pay \( p_s = \Psi_s c^1 \), while a PAYS insuree that is found to be a fast driver would pay \( p_f = \Psi_f c^1 \). Finally, an insuree that wants to have conventional vehicle insurance could be offered the pre-
mium $p_f = \Psi_f c^1$. Notice that the motorist’s freedom of choice is limited to the choice between different schemes and insurance companies because vehicle insurance is compulsory.

This set of premiums would make a fast driver indifferent between choosing PAYS and the conventional scheme from company A, while a slow driver would prefer PAYS. However, fast drivers would prefer switching to any of the other insurance companies (as 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 car drivers insure at the other companies.\(^{10}\) Alternatively, the other companies can also offer the PAYS scheme and will be thus able to retain the low risk group.\(^{11}\)

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

$$
(1-n_s-n_f) \cdot \lambda_s = w + p_s \\
(1-n_f) \cdot \lambda_f = \bar{z} + p_f - p_s
$$

\(^{10}\) In fact, a similar separation can already be observed to some extent on the vehicle insurance market with respect to alcohol drinking. For instance in Sweden, the insurance company MHF only accepts teetotalers.

\(^{11}\) This analysis 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.
non-car to slow car and from slow car to fast car, respectively). Since the value of time is assumed to be uniformly distributed of the population of commuters, simple expressions are held for the value of time at the two margin points. The right hand side of eq. (10a) shows the cost of driving a slow car (operation cost and insurance), while the right hand side of eq. (10b) shows 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, $\Psi_f(\hat{n}_s \hat{n}_f) > \Psi(\hat{n}_s \hat{n}_f) > \Psi_s(\hat{n}_s \hat{n}_f)$ for any pair $(\hat{n}_s \hat{n}_f)$, we get Proposition 1:

**Proposition 1.** A change from conventional vehicle insurance to PAYS insurance will increase the number (share of all commuters) of car drivers and reduce the number (share) of fast cars.

Whether the number of accidents will increase or decrease 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 sign of 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.

From the perspective of the insurance industry, however, two motives for introducing PAYS vehicle insurance can be noticed. First, it increases the market as car ownership increases, and second, the number of high risk drivers decrease. Although we do not explicitly model the objectives of insurance companies in this analysis\(^{12}\), 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

---

\(^{12}\) Given actuarial pricing they always make zero profits. Absent customer loyalty, and as premiums are quoted before contracting, competition is perfect.
also the costs covered by other insurance companies. As a consequence, there is an externality from its change of policy.

### 4.2 Various motives for a vehicle insurance tax

We now introduce a proportional (ad valorem) vehicle insurance tax, $\theta$. The total (gross) premium of a conventional vehicle insurance will then be $p = \psi c^1(1 + \theta)$, while the premiums with PAYS become $p_z = \Psi_z c^1(1 + \theta)$ and $p_f = \Psi_f c^1(1 + \theta)$. There are several different motives for this tax, and we will consider four different cases with (combinations of) motives.

**Case 1:** Internalization of marginal effects. Edlin and Karaca-Mandic (2006) 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 societal cost that is covered by vehicle insurance, which here is denoted $c^1$. Given this focus, a vehicle insurance tax would 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. Assuming that the marginal accident risk is meant to be the average marginal risk, this implies the following tax equation that corrects for the accident externality, i.e., the relative difference between marginal and average risk

$$\Theta = \frac{\psi}{\Psi} - 1. \quad (7)$$

**Case 2:** Internalization of public budget costs. The Swedish government imposed a 32 percent 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. that is caused by traffic accidents (“regress rights”), while the legislative work on launching such a

---

13 With due account to the risk heterogeneities accounted for by variables available to insurance companies.
14 Since commuting distance is fixed in our model the total car traffic work can only be affected by mode choice.
system was being carried out. Such a tax was thus motivated by the cost component that here is called $c^2$. Since the total tax revenue would be limited to total expenditure, this motive is distinctly different from the externality motive for the tax in Case 1. The tax would then, both with conventional and PAYS insurance, correct for the fiscal externality, i.e.,

$$\Theta = \frac{c^2}{c^2}.$$  \hspace{1cm} (8)

**Case 3:** Combination. Correcting for both the accident externality and the fiscal externality with respect to public funding yields the following expression

$$\Theta = \frac{\Phi(c^2 \psi + c^2)}{\psi c^2} - 1$$  \hspace{1cm} (9)

**Case 4:** Combination, including costs for pain and grief. Correcting for the accident externality, the fiscal externality and the externality with respect to costs not covered by insurance (pain and grief) yields

$$\Theta = \frac{\Psi c^2}{\psi c^2} - 1$$  \hspace{1cm} (10)

Comparing these equations, it is clear that only eq. (10) is based on the total social accident cost. However, the tax rate in this case still does not impose the exact marginal cost on a driver of a specific risk type, as the marginal risk in this equation is the average marginal risk for both risk categories. Obviously, both the average marginal risk and the average risk will depend on the number of car drivers and the number of speeders, and therefore on how the tax affects individual behavior. We will now see how the modal mix is affected and how it will be affected by different vehicle insurance schemes and by a vehicle insurance tax.

**Effects of vehicle insurance tax with conventional insurance**

15 In fact, the government decided in 2009 not to enact such a legislation while the tax still remains.
With conventional vehicle insurance, \( p_s = p_f = p \). This is so independent of whether an insurance tax is levied or not. 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 the total accident cost of a careful driver is \( C_{\Psi_s} \) and equation (10) is applied, i.e., when the tax is designed to make drivers account for total social costs as well as the externality, this imposes an insurance premium on this type with \( p = C_{\Psi > C_{\Psi_s}} \). Proposition 3 follows.

**Proposition 3.** With conventional insurance, a vehicle insurance tax determined by eq. (10) will reduce the number (share) of motorists below what is warranted by internalization of the total external cost of accidents.

### 4.4 First best solution with speeding fines or vehicle insurance tax and PAYS

Our analysis includes two market decisions that a regulator would like to affect, i.e. commuters' choices on driving vs. no driving and motorists' choices on speeding vs. no speeding. Two instruments are then required to establish a first best solution. In this section we compare two pairs of such instruments that, in principle, could be used for this end.

**Taxes only.** In a standard Pigovian setting the state regulator can use two taxes, a vehicle tax, \( \tau \), and a speeding penalty, \( \xi \). Each is set equal to the non-internalized marginal cost of accidents from an additional driver and an additional speeder, respectively, i.e.,

\[
\tau = C\Phi_s - p = c^1(\Phi_c - \Psi) + (c^2 + c^3)\Phi_s, \tag{11a}
\]

and

\[
\xi = C(\Phi_f - \Phi_s). \tag{11b}
\]

As we have already observed, an optimal set of these two taxes is often unlikely
to be feasible. No taxes, not even Pigovian taxes, are a free lunch, and in particular the cost of detecting and sanctioning speeding by external monitoring is very costly.

*Combination of PAYS and taxes.* The question therefore is whether PAYS insurance can be exploited as an instrument to reach the first best. In fact, if insurance companies offer PAYS insurance this is possible by use of a vehicle tax ($\tau$) and a tax on vehicle insurance ($\theta$). A first best solution can then be derived from the following equation system

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

(12a)

and

$$\tau + p_f = \tau + c^1 \Psi_f (1 + \theta) = C \Phi_f.$$  

(12b)

This gives the following first best tax formulas

$$\tau = C \Phi_s - p_s = C \Phi_f - p_f.$$  

(13a)

$$\theta = \frac{C \Phi_f - \Phi_s}{c^1 \Psi_f - \Psi_s} - 1$$  

(13b)

These equations imply that the vehicle tax is used to provide correct incentives for a commuter’s decision on whether to drive or not (notice that eq. (13a) is equal to eq. (11a)), while the vehicle insurance tax calibrates the incentives for a motorist’s decision between speeding and non-speeding. The rate of the latter tax therefore depends on the quota 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 a PAYS insurance\(^{16}\),

---

\(^{16}\) However, if PAYS insurance is added on the top of PAYD insurance, the incremental cost is likely to be very low.
resources could be saved by reducing the costs for external monitoring and sanctioning of speeding.

5. Numerical calculations

The purpose of this section is to illustrate the consequences of the alternative solutions derived in section 4 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 percent of GDP, while the full social cost including non-monetary costs of suffering is 1.8 percent 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.

<table>
<thead>
<tr>
<th>Costs</th>
<th>Suffering, $c^3$</th>
<th>Material $c^1+c^2$</th>
<th>No. of individuals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>17 079</td>
<td>1 304</td>
<td>440</td>
</tr>
<tr>
<td>Severe injury</td>
<td>6 306</td>
<td>1 565</td>
<td>3 915</td>
</tr>
<tr>
<td>Light injury</td>
<td>285</td>
<td>156</td>
<td>22 544</td>
</tr>
<tr>
<td>Property only</td>
<td>0</td>
<td>99</td>
<td></td>
</tr>
</tbody>
</table>

Table 1a: Accident costs (thousands SEK) and number of individuals in road traffic accidents for 2005. Available at [www.trafikverket.se](http://www.trafikverket.se)

| Property costs, $c^1$         | 99                |
| Hospital care and production loss, $c^2$ | 281                |
| Suffering, $c^3$              | 1 436             |
Table 1b: Three components of the average cost of road accidents 2005, in thousands SEK.

For this analysis total passenger kilometers with different modes are used as our proxy for \( n \). The car mode accounts for 77 percent of total traffic (68 billion personal car kilometers)\(^{17}\), which would then correspond to \( n_s+n_f \) used in the model. Communications with Road Administration officials indicate that an estimated 57 percent of drivers exceed the going speed limit, meaning that we assume \( N^*n_s=29 \) and \( N^*n_f=39 \) billion km.

Table 1a shows that 26 899 individuals were injured or killed 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 80 percent of all accidents, meaning that \( G_s=5380 \) and \( G_f=21519 \). From this it follows that \( \Psi_s=1.85 \times 10^{-7} \) and \( \Psi_f=5.60 \times 10^{-7} \).

Using these numbers we have calculated the average expected property cost and compared to current insurance (liability) premiums that can be derived on price comparison web sites.\(^{18}\) This indicates that current premiums are four times as high. Since this includes the current 32 percent vehicle insurance tax, we will use a calibration factor of 3 (\( \approx 4/1.32 \)) for comparison with the current net-of-tax vehicle insurance premium level.

Finally, we need to make assumptions about the different marginal risk concepts used in the analysis. Since we do not have empirical evidence of the size of these, we initially do calculations for three sets of numerical values, denoted by A, B and C, representing an increasing degree of convexity of the accident functions. Table 3 summarizes the assumptions made about these numerical values.

\(^{17}\) Official Swedish statistics, available at www.trafa.se.

\(^{18}\) See www.compris承办的se.
<table>
<thead>
<tr>
<th></th>
<th>( \frac{\delta G_s}{\delta n_s} )</th>
<th>( \frac{\delta G_s}{\delta n_f} )</th>
<th>( \frac{\delta G_f}{\delta n_f} )</th>
<th>( \frac{\delta G_f}{\delta n_s} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>( 1 \times \psi_s )</td>
<td>( 1 \times \psi_s )</td>
<td>( 1 \times \psi_f )</td>
<td>( 1 \times \psi_f )</td>
</tr>
<tr>
<td>B</td>
<td>( 1.1 \times \psi_s )</td>
<td>( 1.3 \times \psi_s )</td>
<td>( 1.4 \times \psi_f )</td>
<td>( 1.2 \times \psi_f )</td>
</tr>
<tr>
<td>C</td>
<td>( 1.1 \times \psi_s )</td>
<td>( 2 \times \psi_s )</td>
<td>( 2.5 \times \psi_f )</td>
<td>( 1.5 \times \psi_f )</td>
</tr>
</tbody>
</table>

Table 3: Assumptions about marginal risks.

Inserting these values into the tax rate equations (7) – (10), we can compute the vehicle tax rates using the equations (7) to (10) in section 4.2 (assuming that behavior is not affected by taxes). The results are found in Table 4.

<table>
<thead>
<tr>
<th>Convexity assumption/Tax equation</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>-38</td>
<td>-20</td>
<td>22</td>
</tr>
<tr>
<td>8</td>
<td>95</td>
<td>95</td>
<td>95</td>
</tr>
<tr>
<td>9</td>
<td>77</td>
<td>128</td>
<td>246</td>
</tr>
<tr>
<td>10</td>
<td>281</td>
<td>391</td>
<td>645</td>
</tr>
</tbody>
</table>

Table 4: Vehicle insurance tax rates, percent of current net-of-tax premiums, using eqs. (7) to (10).

The first row of Table 4 shows vehicle insurance tax rates for Sweden that can be compared to the non-internalized externalities in various U.S. state estimated by Edlin and Karaca-Madic (2005). In their analysis, corresponding rates were found to be approximately -5 percent for low traffic-density states such as North and South Dakota and Montana and 50 percent for moderate-density states such as Maine, Kentucky and South Carolina, while our results range from -38 to 22 percent. Since Sweden probably should count as a moderate density state in this comparison, it seems that the “most convex” case C in fact is based on rather conservative assumptions. We will therefore focus on this case.
The second row of Table 4 shows that a full remuneration of public expenditure caused by traffic accidents in Sweden would require a vehicle insurance tax tax at 95 percent, i.e., three times more than the current tax rate (32 percent). The third and fourth row shows that the rate increases to 246 and 645 percent, respectively, if set so as to cover non-internalized externalities at the levels that correspond to monetary costs of accidents (including public expenditure) and full social cost.

Continuing to optimal taxes, Table 5 shows the computed tax rates for the optimal vehicle tax (eq. 11a or 13a), the optimal “Pigovian” expected speeding fine (eq. 11b) and the optimal vehicle insurance tax with PAYS. Once again, behavior is assumed to not be affected. A simple way to apprehend the magnitude of the vehicle tax and the expected speeding fine is by comparison to the fuel cost of a new medium-size car which is approximately 1 SEK/km. The total cost of driving a medium-size car is usually estimated at 3-4 SEK/km.

The first row of numbers show the case when the internalization target concerns the full social cost of accidents, i.e., including the pain and grief component, while the second row shows the corresponding numbers when only monetary cost components are considered. In the first row, we see that the optimal vehicle tax adds 1.77 SEK/km for the driver that complies to speeding rules, while speeders get an additional 1.31 SEK/km on top of that. For an average driver that goes 15 180 km/year), speeding tickets per year would sum to SEK 20,000 (= USD 3,200, Euro 2,300). These numbers, however, are reduced to just one fifth or less, if only the monetary costs of accidents are considered. Still, however, a considerable part of an optimal Pigovian taxation on cars should be the part paid through the speeding fine.

The third row of numbers in the table shows that with PAYS insurance, an optimal vehicle insurance tax that internalizes the full cost of speeding is 300 percent. If only monetary accident costs are considered, this tax becomes negative, indicating that the differentiation with respect to speeding made by insurance companies then slightly exceeds the socially optimal differentiation.
<table>
<thead>
<tr>
<th></th>
<th>Full cost</th>
<th>Only monetary costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle tax (τ)</td>
<td>1.77</td>
<td>0.28</td>
</tr>
<tr>
<td>Expected fines (ξ)</td>
<td>1.31</td>
<td>0.28</td>
</tr>
<tr>
<td>Insurance tax (θ)</td>
<td>296</td>
<td>-17</td>
</tr>
</tbody>
</table>

Table 5. Tax rates, SEK/km (τ and ξ) or percent (θ). One SEK ≈ 11 cent Euro, 16 cent USD. Calculations based on convexity assumptions Case C.

Finally, what would the effects be on accidents from PAYS insurance? This is of course very difficult to say. However, some studies indicate that PAYD insurance affect driving behavior. For instance, in a reported field test by Progressive Insurance Company (2008) with 3000 drivers in Texas it was found that participants on average reduced their miles driven by an average of five percent. Bordoff and Noel (2008) calculate that a full implementation of PAYD insurance would lead to an eight percent reduction of car traffic work in the U.S. Further, a randomized vehicle field trial in Sweden with a sample of 114 drivers, biased towards already carefully driving individuals, found that those provided with an incentive scheme similar to a PAYS insurance reduced time driving above speed limits by 50 percent, compared to a reference group of drivers that had speed alert devices but were not given monetary incentives to reduce speeding (Hultkrantz and Lindberg 2012).

For reference, a 10 percent reduction of accidents19, could be accomplished with our data by a reduction of the number of speeders by 12.5 percent, assuming that the total number of motorists is constant.

---

19 Using the ETSC (2010) accident-average speed relationship, this implies a reduction of average speed by 2 Km/h.
6. Further discussion of the use of insurance for internalization of speeding externalities

There are two sides to the role of vehicle insurance for the prevalence of road accidents. 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 1982, 1987 and 2000). Empirical studies that exploit various natural experiments created by changes of legislation in different states in the U.S. 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.

The information and communication technologies now bring new possibilities for usage-based insurance schemes. Previous literature 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 monitored, and in fact some of these are already used for providing vehicle insurance schemes. For instance, in Sweden one insurance provider charges a lower premium to vehicle owners that have an alco-lock that makes it impossible to use the vehicle for an intoxicated driver.

Such schemes may allow insurance companies both to reduce moral hazard and to achieve a better risk classification and thus reduce adverse selection. What we want to emphasize in this article however is that it also opens up new possibilities for traffic policy.

Traffic policy is normally the business of state or local government regulators, while vehicle insurance is generally provided by insurance companies on market terms. It may be thought therefore that indirect control of car drivers via differentiation of insurance terms would be inferior to direct charges or taxes on drivers. However, insurance companies have several 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.

It should also be observed that 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 needed to be recorded 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). Moreover, a basic idea in this paper is that PAYS is installed on a voluntary basis, making it possible for drivers to self-select with due account of their preferences for being monitored.

7. Conclusions

This paper suggests that PAYS can be seen as a tool for using the insurance industry as an instrument for the government’s traffic safety policy. One shortcoming of traditional policy instruments, not least fuel and vehicle taxation, is their limited ability to differentiate according to behavior. The insurance industry today is already much better at this in its attempts to identify good and bad risks and differentiate the insurance policy accordingly. PAYS would provide a powerful tool to be even more accurate. Even if speed is not the reason for a number of accidents, lower speed may have made it possible to avoid a collision and its consequences.
Our numerical estimates indicate, though, that while PAYS insurance may provide a more efficient instrument to detect and price speeding behavior, full internalization is not possible as long as not all social accident costs are paid by the vehicle insurance premium. Requiring vehicle insurance to cover costs that today in some countries are funded by public finance, such as costs of hospital care, represents a step in that direction. To come close to full internalization, however, it would at first seem necessary to levy a tax on vehicle insurance that reflects the non-monetary costs of pain and grief that represent the lion’s share of the total cost of road accidents for the society.

The good news is, however, that our theoretical analysis shows that with PAYS insurance such a tax can be designed so that speeding tickets are not required at all. 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.

A caveat to this statement should be borne in mind, though. We have assumed that vehicle insurance is compulsory and that all drivers actually pay. However, even when vehicle insurance only has to cover material damages to vehicles, 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. However, as monitoring of non-insured vehicles is as a rule considerably more easy than monitoring of speeding we regard this as a minor objection.

References


ETSC, 2010, Road Safety Target in Sight: Making up for lost time. 4th Road Safety PIN Report.


Law and Contemporary Problems 33, 464-487.