

Better Safe than Sorry?

Ex Ante and Ex Post Moral Hazard in Dynamic Insurance Data

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Abstract

This paper analyzes ex ante and ex post moral hazard in car insurance using Dutch longitudinal micro data. We specify a dynamic model of an insuree's dynamic risk (ex ante moral hazard) and claim (ex post moral hazard) choices. We use this model to characterize the heterogeneous dynamic changes in incentives to avoid claims that are generated by the Dutch experience-rating scheme. We then develop semi-parametric methods that exploit these predictions and data on claim times and sizes to test for moral hazard. We find some evidence of moral hazard.

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1 Introduction

This paper provides an empirical analysis of ex ante and ex post moral hazard in car insurance. Ex ante moral hazard entails that agents respond to changes in incentives by changing the risk of losses. Ex post moral hazard concerns the effects of incentives on claiming actual losses. The distinction between ex ante and ex post moral hazard is important because of their different welfare consequences (e.g. [Chiappori, 2001](#)). Moreover, our empirical analysis is based on a theory of ex ante and ex post moral hazard that connects moral hazard to data on both claim rates and sizes, and thus facilitates more careful inference on moral hazard *per se*.

As in [Abbring et al. \(2003\)](#), our empirical analysis exploits the dynamic variation in incentives to avoid claims generated by experience rating. We use longitudinal micro data on claims from a Dutch insurer and develop tests of absence of moral hazard that have power against moral-hazard alternatives that are likely to arise under the bonus-malus scheme used in the Netherlands.

To support the analysis of these tests, we present a dynamic model of an agent's optimal savings, loss prevention effort, and claim choices under this scheme. The model is an extension of [Abbring et al.'s \(2003\)](#) model with heterogeneous losses and endogenous claiming, carefully adapted to the Dutch institutional environment. We use this model to characterize the dynamic incentives inherent to the Dutch bonus-malus scheme, and their behavioral consequences under moral hazard. Ex ante moral hazard is captured by the endogenous loss prevention effort; ex post moral hazard by the endogenous claim choice. Endogenous savings allow for self-insurance. As a corollary, we prove that [Abbring et al.'s \(2003\)](#) key result linking moral hazard to state dependence of claim rates survives an extension to endogenous claiming.

We first focus on the timing of claims within a contract year. Theory predicts that incentives to avoid claims jump after each claim, so that we can test for moral hazard by testing for state dependence in the claims process, correcting for unobserved heterogeneity

and time effects. A novel theoretical implication for the Dutch case is that incentives to avoid a claim do not always jump up when a claim is filed, but may also jump down or stay put, depending on the agent's current bonus malus class. We use this to improve the power of the tests. Relatedly, our theory's predictions on changes in incentives over time, and their interaction with the agent's bonus-malus state, are used for additional moral hazard tests and to address econometric concerns about time effects.

We also extend [Abbring et al.'s \(2003\)](#) empirical analysis by analyzing the sizes of claims. Under the assumption that ex ante moral hazard only affects the occurrence, but not the size, of insured losses, the latter are informative on ex post moral hazard. We complement this analysis of ex post moral hazard with data on claim withdrawals. In the Netherlands, agents can withdraw a claim within six months and avoid malus. Under some assumptions, which we spell out in detail, claim withdrawals are directly informative on ex post moral hazard.

Unlike [Abbring et al. \(2003\)](#), and in contrast to much of the evidence they review, we find some traces of moral hazard in car insurance. The novel aspects of our approach account for this new evidence, which comes from the new tests that exploit the interaction between state dependence and bonus-class, claim sizes, and claim withdrawals.

The remainder of the paper is organized as follows. [Section 2](#) briefly discusses the market in which the insurance company that provided our data operates, with specific attention for the bonus-malus scheme used. It also introduces the data. [Section 3](#) develops the theory. We use the theory to analyze the dynamic incentives inherent to experience rating, and to derive the implications of moral hazard for claim rate and size dynamics. [Section 4](#) develops an econometric framework for testing the effects of moral hazard from data on claim rates and sizes and presents the empirical results. [Section 5](#) concludes. [Appendices A and B](#) provide proofs and computational details for [Section 3](#). [Appendix C](#) provides more information on the data.

2 Institutional Background and Data

2.1 Experience Rating in Dutch Car Insurance

Early 2006, the 16.3 million inhabitants of the Netherlands were driving 7.1 million private cars.¹ Because liability insurance is mandatory in the Netherlands, this comes with a substantial demand for car insurance. Around 2000, well over a hundred insurance companies served this demand.² Even though these companies are supervised by the Dutch financial authorities, they are to great extent free to set their premiums and contractual conditions. In doing so, the Dutch insurance companies, united in the Dutch Association of Insurers, have coordinated on a mostly uniform experience-rating system in car insurance.

The limited experience-rating that characterized car insurance before 1981 was considered inadequate to price observed risk. At the end of 1981, it was replaced by the *bonus-malus (BM) system* that is still used today (de Wit et al., 1982). This system offers substantial discounts to insurees with few claims, and charges considerably higher rates to insurees with many claims. In it, the premium decreases after each claim-free year and increases with each occurrence of a claim at fault.

The premium discount depends on the insuree's current *bonus-malus class*, which is determined at each annual contract renewal date. Twenty bonus-malus classes are distinguished, from 1 (highest premium) to 20 (lowest premium). Every new insuree starts in class 2 and pays the corresponding premium. We will refer to this premium as the *base premium*. After each claim-free year, an insuree advances one class, up to class 20. Each claim at fault sets an insuree back into a lower class. The worst class is 1, and implies a surcharge to the base premium. This paper uses data from a major Dutch insurance company that uses the bonus-malus scheme given in Table 1. This scheme is representative for the bonus-malus schemes used in the Netherlands.³

¹Source: Statistics Netherlands (www.cbs.nl).

²Source: Dutch Association of Insurers (www.verzekeraars.nl).

³We compared this scheme to schemes offered by other Dutch insurers and found no significant differences. Sometimes, class 14 offered a discount of only 70% and class 1 imposed a surcharge up to 25%.

The empirical analysis in this paper exploits that the incentives to avoid a claim change with each claim filed, and that these changes may differ across bonus-malus classes. To gain some first insight in the differences in the “cost” of a claim to an insuree across different bonus-malus classes and different numbers of claims, we have computed the change in the premium at the next renewal date with each claim in a contract year, for different bonus malus classes. Table 2 gives the percentage premium change after a claim-free contract year, and the subsequent marginal percentage changes in the premium after each claim in the contract year. For example, after a claim-free year in class 8, an insuree will be upgraded to class 9 and pay 45% instead of 50% of the base premium. This amounts to a 10% reduction in the premium. If she files one claim in the contract year, she will instead be downgraded to class 4 and pay 80% of the base premium. This amounts to a $(80 - 45)/45 = 78\%$ increase relative to the premium that would be paid without the claim. A second claim would take her down further to class 1, and a premium equal to 120% of the base (a 50% increase relative to having one claim). A third claim would have no further effect on the premium.

Clearly, unlike the French scheme studied by [Abbring et al. \(2003\)](#), this scheme is not proportional. The premium increases after a first claim are largest for those in the intermediate bonus-malus classes, and smallest for those in the top and bottom classes. The marginal premium increases after a second or third claim, however, are increasing nearly monotonically with the bonus-malus class, from 0% in the lowest classes to 100–140% in class 20.⁴ This all suggests that incentives to avoid a claim jump down after a first claim for insurees in low classes and jump up after a first claim for insurees in high classes. In Section 3, we formally define incentives in a dynamic theoretical setting and provide some numerical computations to formalize this intuition.

Moreover, many insurance companies offer collective insurance with more advantageous BM schemes.

⁴In the lowest classes, therefore, the bonus-malus scheme itself does not give incentives to avoid a second or third claim. However, the insurance company reserves the right to cancel contracts with three or more claims at fault in a year. Because claims-at-fault are fairly rare, this is unlikely to affect insurees’ decisions a lot. Therefore, we ignore contract cancellations in our theoretical and empirical analysis.

Finally, note that insurees are contractually obliged to claim all their insured losses as soon as possible. However, the contract leaves them the option to withdraw their claims within six months from the loss date. Withdrawn claims do not count as at-fault claims in determining the insuree’s bonus-malus class and therefore do not affect the premium. In Section 4, we will use some information about withdrawn claims to learn about ex post moral hazard.

2.2 Data

Our data provide the contract and claim histories of a Dutch insurer’s car insurance clients from January 1, 1995 to December 31, 2000. The raw data consist of 1,730,559 records. Each record registers a change in a particular contract (renewal date, change of car, etcetera), or a claim. The data include 75 variables, with information on drivers, cars, contracts, and claims. We exclude the year 1995 because the data have no information about claims in 1995. This leaves 142,175 unique contracts with a total of 101,816 claims. Of these claims, 33,444 are claims at fault that may lead to a malus.⁵ Appendix C provides details.

We focus on the claims at fault in the first full contract year observed for each contract in the data set. Thus, we construct a sample of first contract years, with information on the times and sizes of claims at fault in these years.⁶ Table 3 gives the number of contracts in our sample by bonus-malus class and by number of claims at fault filed in the contract year. The majority of contracts is in the highest class (20), which corresponds to the lowest premium. Contracts with one claim and contracts with two or more claims will be important, for different reasons, to our empirical analysis. There are a lot of contracts with one claim in our sample but, because claims are rare, there are only 331 contracts

⁵The data include so called “nil” claims, which are mostly pro forma claims of amounts below the deductible. These may correspond to an “at fault” event, but typically do not affect the agent’s bonus-malus status. Therefore, we treat all nil claims as claims not-at-fault. The Appendix provides some further details.

⁶We exclude a small number of contracts that are not covered by the bonus-malus scheme; these are usually contracts covering companies’ fleets of cars against a fixed commercial premium.

with at least two claims.

Figure 1 plots the shares of contracts in our sample with at least one and at least two claims at fault, by bonus-malus class. These shares drop substantially with the bonus-malus class. It may be tempting to relate this variation in the number of claims over bonus-malus classes to our discussion of incentives. However, the overall pattern can be well explained by heterogeneity in risk, with high-risk individuals sorted into the lower bonus-malus classes.

Remarkable spikes are found in classes 6 and 14. The effects of sorting on risk are likely to be smooth, and do not explain these spikes. Interestingly, classes 6 and 14 are the classes in which Table 2's naively computed costs of a first claim start decreasing as a function of K . One explanation of the kinks may therefore be decreases in incentives when moving from classes 5 and 13 to 6 and 14 that have moral-hazard effects that are larger than the decrease in average risk due to sorting. The purpose of our empirical approach is to come up with more robust and convincing ways of separating sorting and moral hazard.

3 A Model of Claim Rates and Sizes

This section characterizes the dynamic incentives to avoid car insurance claims that are inherent to the Dutch bonus-malus scheme. We do so by analyzing a model of a single agent's risk prevention and claim behavior that combines features of Mossin's (1968) static model of insurance and Merton's (1971) continuous-time analysis of optimal consumption. Our model is related to Briys's (1986), but focuses on experience rating and its moral hazard effects. Unlike Abbring et al.'s (2003) analysis of experience rating in French car insurance, we make the nonstationarity arising from annual premium revision explicit. This is important for our empirical analysis because in the Dutch bonus-malus system, unlike in the French one, both the number of past claims and their distribution across contract years matters for the current bonus-malus status.

3.1 Primitives

We consider the behavior and outcomes of an agent i in continuous time τ with infinite horizon. Time is measured in contract years and has its origin at the moment the agent entered the insurance market.

The wealth of agent i at time τ is denoted by $W_i(\tau)$ and accumulates as follows. At time 0, agent i is endowed with some initial wealth $W_i(0)$. Then, between τ and $\tau + d\tau$, agent i receives a return $\rho W_i(\tau)d\tau$ on her wealth and consumes $c_i(\tau)d\tau$. We ignore any other income, such as labor income.⁷

The agent causes an accident between τ and $\tau + d\tau$ with some probability $p_i(\tau)d\tau$.⁸ If so, she incurs some monetary loss. Denote the j -th loss incurred by agent i by L_{ij} . We assume that L_{ij} is drawn independently of the agent's insurance history, including $(L_{i1}, \dots, L_{i(j-1)})$, from some time-invariant distribution F_i .⁹ The losses L_{ij} are covered by an insurance contract involving a fixed deductible D_i and a premium $q_i(\tau)d\tau$ that is paid continuously. The deductible is applied on a claim-by-claim basis, i.e. if a claim for a loss L_{ij} is filed, the insurer pays $L_{ij} - D_i$ to the agent.

The premium $q_i(\tau)$ is determined by agent i 's bonus-malus class $K_i(\tau)$ according to Table 1. Thus, we can write $q_i(\tau) = \pi_i(K_i(\tau))$, where π_i is a mapping from agent i 's bonus-malus class into her flow premium. Because the base premium to which the discounts in Table 1 are applied depends on agent i 's characteristics, the mapping π_i will be heterogeneous across agents.¹⁰

Agent i is endowed with an initial bonus-malus class $K_i(0)$. The bonus-malus class is

⁷For the purpose of our analysis, this is equivalent to assuming that any such income is perfectly foreseen by the agent (Merton, 1971, Section 7).

⁸Accidents that are not caused by the agent are fully covered and have no impact on future premiums. Such accidents can be and are disregarded in our analysis. From now on, by accident or claim we always mean accident or claim *at fault*.

⁹This assumption is quite strong because agent can influence F_i a priori by choosing to drive more or less carefully. Since this choice originates from ex ante moral hazard, we cannot clearly disentangle ex post moral hazard from the latter. However, we can still test for general moral hazard effects.

¹⁰Here, we abstract from time-varying characteristics other than K_i . There is not much harm in treating e.g. age as a time-invariant characteristic, as our empirical analysis will focus on events in only one or a few contract years.

updated at the beginning of each contract year, the renewal date, according to the rule in Table 1. Thus, $K_i(\tau)$ is a right-continuous process, with discrete steps at each renewal date $\tau \in \mathbb{N}$ depending on the past contract year's bonus-malus class and number of claims. Denote by $N_i(\tau)$ the number of claims in the ongoing contract year up to and including time τ . That is, $N_i(\tau)$ is a claim-counting process that is set to zero at the beginning of each contract year. Then, at each renewal date $\tau \in \mathbb{N}$,

$$K_i(\tau) = B(K_i(\tau-), N_i(\tau-)),$$

where $K_i(\tau-)$ and $N_i(\tau-)$ are agent i 's bonus-malus class and number of claims in the past contract year, respectively, and B represents Table 1's bonus-malus updating rule. Note that this rule is common to all agents. Recall that it moves agents who survive a contract year without claims to a higher bonus-malus class, corresponding to a lower premium, and all other agents to a lower class, with a higher premium.

Insurance claims filed by the agent are potentially affected by ex ante and ex post moral hazard (Chiappori, 2001). Ex ante moral hazard arises if the agent can affect the probability of an accident. We model this by allowing, at each time τ , the agent to choose the intensity $p_i(\tau)$ of having an accident from some bounded interval $[\underline{p}_i, \bar{p}_i]$, at a utility cost $\Gamma_i(p_i(\tau))$. We assume that Γ_i is twice differentiable on $(\underline{p}_i, \bar{p}_i)$, with $\Gamma'_i < 0$, $\Gamma''_i > 0$. In words, reducing accident rates is costly and returns to prevention are decreasing. For definiteness, we also assume that $\Gamma'_i(\underline{p}_i+) = \infty$ and $\Gamma'_i(\bar{p}_i-) = 0$. In addition, we allow for ex post moral hazard by allowing the agent to hide a loss she has actually incurred from the insurer. We assume that claiming and hiding losses are costless, but that the agent cannot claim losses that have not actually been incurred.

The agent's instantaneous utility from consuming $c_i(\tau)$ and driving with accident intensity $p_i(\tau)$ at time τ is $u_i(c_i(\tau)) - \Gamma_i(p_i(\tau))$. We assume that u_i is increasing and strictly concave, so that the agent is risk-averse. The agent chooses consumption, prevention and

claiming plans that maximize total expected discounted utility¹¹

$$\mathbb{E} \left[\int_0^\infty e^{-\rho\tau} [u_i(c_i(\tau)) - \Gamma_i(p_i(\tau))] d\tau \right],$$

subject to the intertemporal budget constraint $\lim_{\tau \rightarrow \infty} e^{-\rho\tau} W(\tau) = 0$ and given the wealth and premium dynamics described above.

At each time τ , the agent observes her wealth, bonus-malus and claim histories. As we have implicitly assumed that any labor and other income is perfectly foreseen by the agent, she only has to form expectations on future accidents and their implications.

3.2 Optimal Risk, Claims and Savings

For notational convenience, we now drop the index i . It should be clear, however, that all results are valid at the individual level, irrespective of the distribution of preferences and technologies across agents. In particular, the results hold for any type of unobserved heterogeneity in these primitives of the model.

Because our model is Markovian and, apart from annual contract renewal, time-homogeneous, the optimal consumption, prevention and claim decisions at time τ only depend on the past history through the agent's current wealth $W(\tau)$, bonus-malus class $K(\tau)$, the number of claims at fault $N(\tau)$, and the time $t \equiv \tau - [\tau]$ past in the ongoing contract year.¹² Let $V(t, W, K, N)$ denote the agent's optimal expected discounted utility at time t in the contract year if her wealth equals W , she is in bonus-malus class K , and has claimed N losses in the ongoing contract year. This value function satisfies the

¹¹For simplicity, we assume that subjective discount rates equal the interest rate.

¹²Like [Abbring et al. \(2003\)](#), we have disregarded alternative channels, such as learning, fear, or cautionary responses to accidents by specifying the prevention technology, as represented by the cost function Γ , to be independent of the accident history.

Bellman equation

$$\begin{aligned}
V(t, W, K, N) = & \\
& \max_{c, p, \mathcal{X}} \left\{ u(c)dt - \Gamma(p)dt + e^{-\rho dt} \times \right. \\
& \quad \left[(1 - pdt)V(t + dt, (1 + \rho dt)W - cdt - \pi(K)dt, K, N) \right. \\
& \quad \left. + pdt \int_{\mathcal{X}} V(t + dt, (1 + \rho dt)W - \min\{l, D\} - cdt - \pi(K)dt, K, N + 1)dF(l) \right. \\
& \quad \left. + pdt \int_{\mathcal{X}^c} V(t + dt, (1 + \rho dt)W - l - cdt - \pi(K)dt, K, N)dF(l) \right] \left. \right\}, \tag{1}
\end{aligned}$$

with

$$V(1, W, K, N) \equiv \lim_{t \uparrow 1} V(t, W, K, N) = V(0, W, B(K, N), 0). \tag{2}$$

Equation (1) can be interpreted as follows. Between t and $t + dt$ the agent derives flows of utility from her consumption and disutility from her prevention effort. The value $V(t, W, K, N)$ equals the net value of these utility flows, at the optimal consumption and prevention levels, plus the expected optimal discounted utility at time $t + dt$. With probability $1 - pdt$ no accident occurs. Then, the agent's wealth is increased with the interest flows minus consumption and the premium, and the number of claims at fault, N , stays unchanged. If she causes an accident, with probability $pd t$, then she will incur an additional wealth loss. The size of this wealth loss is subject to ex post moral hazard. If L lies in the optimal choice of the *claim set* \mathcal{X} , she claims for insurance compensation and only loses the minimum of the loss L and the deductible D . Then, the number of claims at fault, N , increases by 1. If L lies in the complement \mathcal{X}^c of the optimal claim set, however, she does not claim and pays the full loss L . Then, the number of claims at fault, N , stays unchanged.

Equation (2) reflects the effects of annual premium renewal. It requires that the value

in class K with N claims just before a renewal time equals the value in class $B(K, N)$ with 0 claims just after renewal.

Bellman equation (1) can be rewritten in a more familiar form by rearranging and taking limits $dt \downarrow 0$,

$$\begin{aligned} \rho V(S) = \max_{c,p,\mathcal{X}} & \left\{ u(c) - \Gamma(p) \right. \\ & + p \left[\int_{\mathcal{X}} V(t, W - \min\{l, D\}, K, N + 1) dF(l) \right. \\ & \quad \left. + \int_{\mathcal{X}^c} V(t, W - l, K, N) dF(l) - V(S) \right] \\ & \left. + V_W(S) [\rho W - c - \pi(K)] + V_t(S) \right\}, \end{aligned} \quad (3)$$

where V_t and V_W are the partial derivatives of V with respect to, respectively, t and W . The left-hand side of (3) is the flow (or perpetuity) value attached by the agent to state $S \equiv (t, W, K, N)$. It equals the (optimal) instantaneous flow of utility from her consumption net of the disutility from her prevention effort plus three expected value (“capital”) gains terms, (i) the expected value gain because of an accident, (ii) the value gain due to net accumulation of wealth, and (iii) the appreciation of the value over time.

Standard arguments guarantee that (3), with (2), has a unique solution V , and that an optimal consumption-prevention-claim plan exists. In Appendix A, we prove that the value function V is strictly increasing in wealth W (Lemma 1) and that it is weakly increasing in the bonus-malus class K and weakly decreasing in the number of claims at fault N (Lemma 2).

One direct implication is that the agent follows a threshold rule for claiming.

Proposition 1. *The optimal claim set in state S is given by $\mathcal{X}^*(S) \equiv (x^*(S), \infty)$, for some claim threshold $x^*(S) \geq D$.*

Thus, if the agent incurs a loss L at time t then, for given wealth W , bonus-malus class K and number of claims at fault N right before t , she claims if and only if $L > x^*(S)$. The threshold is implicitly defined as the loss at which she is indifferent between claiming

and not claiming:

$$V(t, W - D, K, N + 1) = V(t, W - x^*(S), K, N). \quad (4)$$

This assumes an internal solution and, in particular, ignores the trivial, and empirically irrelevant, case in which $\mathcal{X} = \emptyset$.

Optimality of the two remaining choices, consumption and prevention, requires that the corresponding first-order conditions are satisfied,

$$u'(c^*(S)) = V_W(S) \quad \text{and} \quad (5)$$

$$\begin{aligned} -\Gamma'(p^*(S)) &= V(S) - \int_0^{x^*(S)} V(t, W - l, K, N) dF(l) \\ &\quad - \int_{x^*(S)}^{\infty} V(t, W - D, K, N + 1) dF(l), \end{aligned} \quad (6)$$

where $p^*(S)$ and $c^*(S)$ are, respectively, the optimal accident and consumption intensities in state $S \equiv (t, W, K, N)$. The first equation is the standard Euler condition, which balances the marginal utilities from current and future consumption. The second condition requires equality of the marginal cost of prevention and the marginal cost of an accident.

3.3 Dynamic Incentives from Experience Rating

3.3.1 A Measure of Incentives

The first-order condition (6) embodies two distinct aspects of ex ante moral hazard, the agent's ability to reduce risk and the incentives she is given to do so. If the interval $[\underline{p}, \bar{p}]$ of possible risk choices p is narrow and, consequently, the marginal cost $-\Gamma'$ of reducing risk quickly increases from 0 to ∞ , changes in incentives have little effect on risk and moral hazard is limited. In the limiting case in which $\Gamma(p) = 0$ if $p \geq p_0$ and $\Gamma(p) = \infty$ if $p < p_0$, for some $p_0 > 0$, the agent will choose an accident rate p_0 irrespective of incentives to avoid claims. We will refer to this limiting case as the case of “no (ex ante) moral

hazard”.

The right-hand side of (6) is the expected discounted utility cost of a claim. This is a measure of the incentives to avoid an accident, for a given prevention technology Γ . In this section, we characterize the variation in these incentives with, in particular, K and N . In the next section, we use this characterization to test for moral hazard.¹³

We focus on the dynamic incentives inherent to the bonus-malus scheme and set the deductible D to 0. This simplifies the presentation and does not greatly interfere with our objective of learning about *changes* in incentives across states. We will also focus on the incentives in the case of no moral hazard. Then, the optimal accident rate $p^*(S)$ equals a fixed number $p_0 > 0$ in all states S and all losses are claimed, and the right-hand side of (6) simplifies to¹⁴

$$V(t, W, K, N) - V(t, W, K, N + 1). \quad (7)$$

We will characterize incentives in the case of no moral hazard by characterizing this difference in utility values as a function of the state (t, W, K, N) . This will be sufficient for interpreting local behavior of econometric tests near the null of no moral hazard.

Before we move to these computations, note that (7) is also a measure of incentives to avoid a claim given that an accident has occurred. Linearizing (4) as a function of the threshold around the deductible $D = 0$ gives

$$x^*(t, W, K, N)V_W(t, W, K, N) \approx V(t, W, K, N) - V(t, W, K, N + 1).$$

The left-hand side of this equation is the marginal cost, in expected discounted utility units and at a time a claim decision needs to be taken, of increasing the threshold just

¹³Abbring et al. (2003) use simpler tests based on unambiguous theoretical results on the change in incentives after each claim in French car insurance. These results rely on the proportional nature of the French bonus-malus system, and do not carry over to the Dutch system.

¹⁴The case of no ex post moral hazard could be explicitly modeled by introducing a cost to the agent of hiding losses from the insurer and setting that cost sufficiently high. There is little gain of making this explicit here.

above the deductible $D = 0$. The right-hand side is again the expected discounted utility cost of a claim in (7).

3.3.2 Theoretical Characterization of Incentives

We compute the value function and the incentives for the constant absolute risk aversion (CARA) class of utility functions, which is given by

$$u(c) = \frac{1 - e^{-\alpha c}}{\alpha},$$

with $\alpha > 0$ the coefficient of absolute risk aversion, $-u''(c)/u'(c)$. Linear utility, $u(c) = c$, arises as a limiting case if we let $\alpha \downarrow 0$. The CARA class brings analytical and computational simplifications that we believe outweigh, for the purpose of this paper at least, its disadvantages (see e.g. Caballero, 1990, for some discussion).

Merton's (1971) results that, with CARA utility, the value and utility functions have the same functional forms and consumption is linear in wealth, provide intuition for

Proposition 2. *In the case of no moral hazard with accident rate p_0 , $D = 0$, and CARA utility,*

$$c^*(S) = \rho [W - Q(t, K, N)] \quad \text{and} \quad V(S) = \frac{1 - e^{-\alpha \rho [W - Q(t, K, N)]}}{\alpha \rho},$$

with $S \equiv (t, W, K, N)$ and Q the unique solution to the system of differential equations

$$\rho Q(t, K, N) = \pi(K) + p_0 \frac{e^{\alpha \rho [Q(t, K, N+1) - Q(t, K, N)]} - 1}{\alpha \rho} + Q_t(t, K, N) \quad (8)$$

$$Q(1, K, N) = Q(0, B(K, N), 0). \quad (9)$$

Here, $Q_t(t, K, N)$ is the derivative of $Q(t, K, N)$ with respect to t .

Proposition 2 is proved in Appendix A. It provides a characterization of the value function V that can be used to compute incentives locally around the null of no moral hazard.

To gain some insight in Proposition 2's characterization of optimal consumption and the value function, first note that equation (8) reduces to

$$\rho Q(t, K, N) = \pi(K) + p_0 [Q(t, K, N + 1) - Q(t, K, N)] + Q_t(t, K, N)$$

if we let $\alpha \downarrow 0$. Thus, in the limiting case of linear utility— that is, a risk-neutral agent— $Q(t, K, N)$ reduces to the expected discounted flow of future premia. The agent simply consumes the flow value $\rho[W - Q(t, K, N)]$ of her *net* wealth, which produces a value $V(S) = W - Q(t, K, N)$. The expected discounted utility cost of a claim in state S is given by

$$V(S) - V(t, W, K, N + 1) = Q(t, K, N + 1) - Q(t, K, N).$$

Conveniently, incentives are independent of the level of wealth in this case.

With a risk-averse agent— that is, for fixed $\alpha > 0$ — the right-hand side of equation (8) involves an additional term,

$$p_0 \left\{ \frac{e^{\alpha\rho[Q(t,K,N+1)-Q(t,K,N)]} - 1}{\alpha\rho} - [Q(t, K, N + 1) - Q(t, K, N)] \right\}.$$

This term is strictly positive for all (t, K, N) . As a consequence, $Q(t, K, N)$ strictly exceeds the expected discounted flow of premia, and optimal consumption is lower than with linear utility. This reflects precautionary savings. Incentives in state S are now given by $V(S) - V(t, W, K, N + 1) = (\alpha\rho)^{-1}e^{-\alpha\rho W} [e^{\alpha\rho Q(t,K,N+1)} - e^{\alpha\rho Q(t,K,N)}]$, so that a wealth-invariant measure of incentives is given by

$$\Delta V(t, K, N + 1) \equiv \frac{V(S) - V(t, W, K, N + 1)}{e^{-\alpha\rho W}} = \frac{e^{\alpha\rho Q(t,K,N+1)} - e^{\alpha\rho Q(t,K,N)}}{\alpha\rho}.$$

Note that this measure again reduces to $Q(t, K, N + 1) - Q(t, K, N)$ if we let $\alpha \downarrow 0$.

3.3.3 Numerical Characterization of Incentives

In the remainder of this section, we will numerically characterize incentives by computing $\Delta V(t, K, N+1)$ for various values of (t, K, N) , α , and p_0 . An algorithm for computing the underlying function Q is presented in Appendix B. We set $\rho = \ln(1.04)$ to be consistent with a 4% annual interest and discount rate. In our baseline computations we take $p_0 = 0.064$, which corresponds to a 93.8% probability of having no claim in the contract year. This equals the share $\frac{106,990}{114,017}$ of contracts in our sample without claims (see Table 3). We measure the premium $\pi(K)$ in multiples of the base premium. That is, $\pi(K)$ is set equal to the premium reported in Table 1 and, in particular, $\pi(2) = 1$.

Figure 2 plots the (wealth-invariant measures of the) present discounted utility costs of a first ($\Delta V(1, K, 1)$) and a second ($\Delta V(1, K, 2)$) claim just before contract renewal, as a function of the bonus-malus class K . The bold graphs correspond to the linear-utility case $\alpha = 0$ and give the expected discounted premium cost of a claim in multiples of the base premium. The other graphs correspond to $\alpha = 0.1, 0.2, \dots, 0.5$, in that order and with the graphs corresponding to $\alpha = 0.1$ closest to the bold graph. At a consumption level equal to 20 times the base premium, $\alpha = 0, 0.1, \dots, 0.5$ correspond to coefficients of *relative* risk aversion equal to $0, 2, \dots, 10$, respectively. This is roughly the range considered, with some empirical support, by Caballero (1990).

Incentives near the null of no moral hazard are considerable. In the linear case, total wealth drops by more than the annual base premium. Recall that the base premium is four times the premium in class 20 paid by most insurees in our sample. The cases with risk aversion are very similar. Incentives also vary a lot between bonus-malus classes. They are small in the lowest classes, where the premium paid is already high. They then increase substantially, and again fall to a lower level in the highest classes. Robustly across values of α , incentives to avoid a first claim are larger than the incentives to avoid a second claim in classes $K < 8$, they are the same at around $K = 8$, and incentives to avoid a second claim are largest for $K > 8$. Thus, for agents in high bonus-malus classes,

the Dutch bonus-malus system has implications that are similar to those of the French proportional experience-rating scheme studied by [Abbring et al. \(2003\)](#): The first claim in a contract year leads to jump up in incentives, and therefore jump down in claim rates under moral hazard. However, the Dutch system allows us to contrast this implication with the effects low bonus-malus classes, where incentives jump *down* after a first claim.

Figure 3 plots the change $\Delta V(1, K, 2) - \Delta V(1, K, 1)$ in incentives to avoid a claim when a first claim is filed just before contract renewal, again for different degrees of risk aversion. This graph again shows that incentives jump down for low K and up for high K . These effects, and those in Figure 2, are computed at a specific point, $t = 1$, in time, but are robust to considering alternative times.

To illustrate this, Figure 3 also plots the changes over the course of a contract year in incentives to avoid, respectively, a first and a second claim. Because $\Delta V(t, K, 1) - \Delta V(0, K, 1)$ and $\Delta V(t, K, 2) - \Delta V(0, K, 2)$ are close to linear as functions of time t , these graphs of $\Delta V(1, K, 1) - \Delta V(0, K, 1)$ and $\Delta V(1, K, 2) - \Delta V(0, K, 2)$ summarize well the time patterns in incentives, and the variation in these time patterns between bonus malus classes. The changes in incentives over time are small relative to the jumps in incentives when a first claim is filed just before contract renewal. The *differences* between $\Delta V(1, K, 1) - \Delta V(0, K, 1)$ and $\Delta V(1, K, 2) - \Delta V(0, K, 2)$ are even smaller. Because these differences give the change in $\Delta V(t, K, 2) - \Delta V(t, K, 1)$ over the contract year, this implies that the graph of $\Delta V(1, K, 2) - \Delta V(1, K, 1)$ indeed characterizes well the jump in incentives at the time of a first claim at all times. Finally, the incentives' time patterns do not vary much between bonus-malus classes.

Even if the time-variation in incentives is small relative to the jumps in incentives at the times of a claim, it may still affect some of our empirical procedures that focus on the latter. After all, the time-variation in incentives affects all contracts, but only some contracts experience jumps in incentives. We will return to this in Section 4 in the specific context of an econometric model.

Finally, we explore the robustness of these results to changes in the accident hazard under the null, p_0 . Figure 4 again plots $\Delta V(1, K, 2) - \Delta V(1, K, 1)$, $\Delta V(1, K, 1) - \Delta V(0, K, 1)$, and $\Delta V(1, K, 2) - \Delta V(0, K, 2)$ for different levels of risk aversion, but for $p_0 = 0$. The graphs are qualitatively similar to those in Figure 3 for the average-risk case. Time effects are smaller in the zero-risk case because agents do not expect another accident during the contract year irrespective of the time of their first claim; time preference is the only source of nonstationarity in this extreme case.

Figure 5 plots the same graphs for $p_0 = 0.4592$, which is the average risk level consistent with the number of contracts without a claim in the worst bonus-malus class, $K = 1$. At this risk level, incentives only increase at the time of a first claim in the highest bonus-malus classes, and decrease at low and intermediate bonus-malus classes. Also, time effects are substantial. Because agents are very likely to experience an accident during the contract year anyhow, incentives do not jump much early in the year even if they would jump a lot close to renewal.

In sum, the qualitative conclusions for our baseline case with average risk continue to hold as long as p_0 is average or low, but change for very large p_0 . Nevertheless, we can robustly conclude that incentives drop at the time of a first claim in all low classes, and increase in the very highest classes.

4 Empirical Analysis

4.1 Econometric Model

Our analysis focuses on the timing and sizes of car insurance claims in a single insurance contract year, i.e. the period bounded by two consecutive contract renewal dates. We first present a model for the population of claim histories in the contract year.

We use Section 3's notation whenever possible. Let time t have its origin at the start of the contract year and let the contract year have length 1. Let T_j be the time and L_j the

size of the j -th claim in the contract year. Denote the corresponding counting process by $N[0, 1] := \{N(t); 0 \leq t \leq 1\}$, where $N(t) := \#\{j : T_j \leq t\}$ counts the number of claims in the contract year up to time t . The claim history $(N[0, 1]; L_1, \dots, L_{N(1)})$, and its relation to the bonus-malus class K occupied by the agent during the contract year, are the focus of our econometric model and empirical analysis.

The intensity θ_l of claims of size $l \in \mathbb{R}$ or up at time t , conditional on the claim history $H[0, t] := (\{N(u); 0 \leq u < t\}; L_1, \dots, L_{N(t-)})$ up to time t , the bonus-malus class K , and a nonnegative individual-specific effect λ is

$$\theta_l(t|\lambda, H[0, t], K) = \theta_0(t|\lambda, N(t-), K) \cdot \bar{F}(\max\{l, x^*(t, \lambda, N(t-), K)\}|\lambda). \quad (10)$$

Here, with some convenient abuse of notation, $\theta_0(t|\lambda, N(t-), K)$ is the rate at which losses are incurred at time t by an agent with characteristics λ in class K who has claimed $N(t-)$ times in the year up to t . The second factor, $\bar{F}(\max\{l, x^*(t, \lambda, N(t-), K)\}|\lambda)$, is the probability that a claim with size in $[l, \infty)$ is filed, conditional on a loss by that same agent in the same conditions. This specification of the conditional claim probability incorporates Section 3's assumption that losses are drawn from an exogenous and time-invariant distribution $F(\cdot|\lambda) = 1 - \bar{F}(\cdot|\lambda)$ that may differ between agents. It also reflects the result that agents follow a threshold rule for claiming (Proposition 1).

Without further loss of generality, and to facilitate a discussion of theory's implications for (10), we write

$$\theta_0(t|\lambda, N(t-), K) = \lambda \cdot \psi(t) \cdot \beta(t|\lambda, N(t-), K), \quad (11)$$

with ψ a continuous and positive function and β an almost surely bounded and positive function. We frequently use the notation $\Psi(t) := \int_0^t \psi(u) du$ and normalize $\Psi(1) = 1$. We assume that λ has distribution G_K conditional on K .

Together with equation (10), this fully specifies the distribution of $(N[0, T]; L_1, \dots, L_{N(1)})|K$.

Our data set is a random sample $\{(N_i(1); T_{1i}, \dots, T_{N(1)i}; L_{1i}, \dots, L_{N(1)i}; K_i); i = 1, \dots, n\}$ from the distribution of $(N(1); T_1, \dots, T_{N(1)}; L_1, \dots, L_{N(1)}, K_i)$.

4.2 Theoretical Implications

First, consider the simplification of (10) that is implied by the absence of moral hazard. In the empirical analysis, we will refer to this case as the *null of no moral hazard*.

Prediction 1. The claims process under the null of no moral hazard. *Without moral hazard, $\beta \equiv 1$ and $x^* \equiv 0$, so that*

$$\theta_l(t|\lambda, H[0, t], K) = \lambda\psi(t)\bar{F}(l|\lambda).$$

Given λ , claim rates and sizes do not depend on the past number of claims $N(t-)$ or the bonus-malus class K ; they only depend on contract time through the function ψ . That is, there is no state dependence in the claims process.

Taken literally, Section 3’s theory implies that $\psi \equiv 1$, so that $\theta_l(t|\lambda, H[0, t], K) = \lambda\bar{F}(l|\lambda)$ is time-invariant, with $\lambda = p_0$. Thus, ψ captures contract-time effects that are *external* to the model, that is, that are independent of the claim history and the bonus-malus class. We entertain the possibility of such effects because, if they are there for some reason, they are likely to confound our analysis of state dependence.¹⁵ We will present both tests that assume $\psi \equiv 1$ (“stationarity”) and tests that allow for nonparametric ψ . The proportional specification of (11) will then capture the first-order effects of any external calendar-time affects. Note that in addition we explicitly allow, through β and x^* , for contract-time effects that arise *internally* because of the fact that contracts are renewed at discrete times. These internal time effects will in general enter the claim rate nonproportionally.

¹⁵The theoretical and econometric models only recognize contract time and do not explicitly consider the effects of calendar time (or duration since last event for that matter). In our sample, different contracts have different renewal dates, so that contract time and calendar time do not coincide. If renewal dates are evenly distributed over calendar time, seasonal calendar-time effects are not likely to matter much to the empirical analysis.

The theoretical analysis of Section 3 can now be applied to predict the properties of the claims process for given λ under local moral-hazard alternatives. First note that the theory implies that incentives to avoid claims vary between classes K . However, in data the resulting moral-hazard effects on claims are confounded with sorting of agents with different characteristics λ into different classes K . The problem of empirically separating these selection effects from the causal effects of incentives is the standard problem of causal inference from cross-sectional data. This is a notoriously hard problem that we avoid here.

Instead, we exploit that there is idiosyncratic variation in incentives over time. For expositional convenience, suppose that there are no external time effects, $\psi \equiv 1$. Then, we have

Prediction 2. Dependence of claims on time t , by class K under moral hazard. *Conditional on λ , loss rates of an agent with 0 or 1 claims (or, more particularly, $\beta(t|\lambda, 0, K)$ and $\beta(t|\lambda, 1, K)$) weakly decrease with t in most classes K , but may increase in the very highest classes. The opposite holds for claim thresholds x^* , so that the effects on loss rates carry over to claim rates. All these time effects are small compared to the jumps at the time of a claim, except for very high loss rates.*

If there are external contract-time effects, that is if ψ is nontrivial, then Prediction 2 holds relative to these external effects.

Prediction 3. Dependence of claims on $N(t-)$, by class K under moral hazard. *Conditional on λ , loss rates jump down ($\beta(t|\lambda, 1, K) < \beta(t|\lambda, 0, K)$) and claim sizes increase ($x^*(t, \lambda, 1, K) > x^*(t, \lambda, 0, K)$) at the time of the first claim in high classes K . In contrast, in low classes K loss rates jump up ($\beta(t|\lambda, 1, K) > \beta(t|\lambda, 0, K)$) and claim sizes decrease ($x^*(t, \lambda, 1, K) < x^*(t, \lambda, 0, K)$) after the first claim. Because the state-dependence effects on loss rates and claim probabilities work in the same direction, the results for the loss rates again carry over to claim rates.*

Predictions 1-3 are all conditional on λ ; they are predictions at the level of an individual contract. Because λ is not observed, tests based on contrasting the predicted behavior under the null (Prediction 1) with the predicted behavior under the moral-hazard alternative (Predictions 2 and 3) are not feasible. The econometric challenge is develop tests that use these predictions without requiring data on λ .

Our tests exploit the dynamics of claims implied by Predictions 2 and 3. Rather than studying cross-sectional variation in incentives, and trying to separate these from selection effects, we exploit variation in incentives over time. The problem of separating the corresponding dynamic moral hazard effects from dynamic selection is the classic problem of distinguishing state dependence and heterogeneity. Like the problem of distinguishing causal effects and selection effects in a static setting, this is a hard problem. However, it is a richer problem that has been well-studied in the statistics and econometrics literature (seminal contributions are [Bates and Neyman, 1952](#); [Heckman and Borjas, 1980](#)). A key result from this literature implies that, under the null, the total number of claims in the contract year is a sufficient statistic for the unobserved heterogeneity in the loss intensities. We use this result to control for unobserved heterogeneity in the loss rates.

With this tool in hand, we first study time effects in claim rates. Prediction 1 implies that, under the null and after controlling for heterogeneity, time effects should be identical between classes K . Moreover, there should be no time effects at all under the theory's assumption of stationarity ($\psi \equiv 1$). On the other hand, both Predictions 2 and 3 imply that there will be time effects under moral hazard.

Time effects in claim rates are likely to be small and tests for moral hazard based on observed time effects are not likely to be very powerful. Therefore, we quickly move to comparing (distributions of) first and second claim times and sizes. Here, Prediction 3 takes center stage. Because the jumps in incentives at the time of a claim are much larger than the time-variation in incentives, Prediction 3's "structural occurrence dependence" ([Heckman and Borjas, 1980](#)) effects dominate Prediction 2's time effects.

Therefore, we can test for moral hazard by testing the implications of Prediction 3 for the relation between first and second claim times and sizes, across classes K and controlling for heterogeneity and, possibly, external time effects.

4.3 Claim Times

In this section, we focus on the timing of claims and ignore information on claim sizes. Section 3 proves that ex ante and ex post moral hazard work in the same direction. Thus, we can view tests based on claim times as overall tests for moral hazard.

4.3.1 The Distribution of the First Claim Time

First consider the distribution of the first claim time T_1 in the subpopulation with exactly one claim in the contract year and in class $K \in \mathcal{K}$,

$$H_1(t|\mathcal{K}) = \Pr(T_1 \leq t | N(1) = 1, K \in \mathcal{K}),$$

and its empirical counterpart

$$\hat{H}_{1,n}(t|\mathcal{K}) = \frac{1}{M_{1,\mathcal{K},n}} \sum_{i=1}^n I(T_{1,i} \leq t, N_i(1) = 1, K_i \in \mathcal{K}),$$

where $M_{k,\mathcal{K},n} \equiv \sum_{i=1}^n I(N_i(1) = k, K_i \in \mathcal{K})$ is the number of contracts in the sample of contracts in a class in \mathcal{K} with exactly k claims.

Under the null of no moral hazard, $H_1(\cdot|K \in \mathcal{K}) = \Psi(\cdot)$ (Prediction 1 and [Abbring et al., 2003](#)). Under the moral hazard alternative, $H_1(\cdot|\mathcal{K})$ will typically depend on the choice of \mathcal{K} and differ from $\Psi(\cdot)$. This variation is caused by both changes in incentives over time (Prediction 2) and changes in incentives at the time of a claim (Prediction 3).

Figure 6 plots $\hat{H}_{1,n}(t|K \in \mathcal{K})$ for $\mathcal{K} = \{1, \dots, 8\}$ and $\mathcal{K} = \{9, \dots, 20\}$. Differences between the two graphs are small but, if anything, suggest that agents in classes $K \geq 9$ file claims later in the year. This is consistent with time effects (Prediction 2), but not

with the effects of an jump up in incentives after the claim (Prediction 3).

However, none of a wide variety of (Kruskal-Wallis, Wilcoxon rank-sum, Kolmogorov-Smirnov) tests, applied with different choices of two or more sets \mathcal{K} , leads to rejection of the null that the $H_1(\cdot|\mathcal{K})$ does not depend on \mathcal{K} . Moreover, we cannot reject that H_1 is uniform, which is the null of no moral hazard under the additional assumption of stationarity ($\Psi \equiv 1$).

These results should be interpreted with care, because Predictions 2 and 3 correspond to only small effects of K on H_1 , and work in opposite directions. Therefore, we now move to a comparison of first and second claim times.

4.3.2 The Marginal Distributions of the First and Second Claim Times

Next consider the distribution of the second claim time T_2 in the subpopulation with exactly two claims in the contract year and in class $K \in \mathcal{K}$,

$$H_2(t|\mathcal{K}) = Pr(T_2 \leq t | N(T) = 2, K \in \mathcal{K}),$$

and its empirical counterpart,

$$\hat{H}_{2,n}(t|\mathcal{K}) = \frac{1}{M_{2,\mathcal{K},n}} \sum_{i=1}^n I(T_{2,i} \leq t, N_i(1) = 2, K_i \in \mathcal{K}).$$

Abbring et al.'s (2003) analysis implies that, under the null of no moral hazard, $H_2(t|\mathcal{K}) = H_1(t|\mathcal{K}')^2$, for all ψ and $\mathcal{K}, \mathcal{K}'$. They also show that this equality breaks down under moral hazard, and is likely to do so in one direction. This suggests a test for moral hazard based on a comparison of $\hat{H}_{2,n}(\cdot|\mathcal{K}')$ and $\hat{H}_{1,n}(\cdot|\mathcal{K})^2$ for appropriate choices of \mathcal{K} and \mathcal{K}' .

Figure 7 plots $\hat{H}_{1,n}(\cdot|\mathcal{K})$, $\hat{H}_{2,n}(\cdot|\mathcal{K}')$, and $\hat{H}_{1,n}(\cdot|\mathcal{K})^2$ for $\mathcal{K} = \mathcal{K}' = \{1, \dots, 7\}$ and for $\mathcal{K} = \mathcal{K}' = \{9, \dots, 20\}$. We find some evidence that $H_2 > H_1^2$ in classes $K \leq 7$ and $H_2 < H_1^2$ in classes $K \geq 9$. From Abbring et al.'s (2003) analysis, we expect the opposite rankings under moral hazard. However, the differences are not significant at any

conventional level.

Unlike [Abbring et al.](#), we can exploit that the effects of claims and time on incentives differ between bonus-malus classes, and pick \mathcal{K} and \mathcal{K}' to maximize power. Figure 8 plots $\hat{H}_{1,n}(\cdot|\mathcal{K})$, $\hat{H}_{2,n}(\cdot|\mathcal{K}')$, and $\hat{H}_{1,n}(\cdot|\mathcal{K})^2$ for $\mathcal{K} = \{8, \dots, 20\}$ and $\mathcal{K}' = \{1, \dots, 7\}$, and for $\mathcal{K} = \{1, \dots, 8\}$ and $\mathcal{K}' = \{9, \dots, 20\}$. By estimating H_2 and H_1^2 on subsamples in which incentives have opposite signs, we increase the power of the test. In this case, little changes. One reason may be that, even though our current choices of \mathcal{K} and \mathcal{K}' are optimal if we only take into account Prediction 3, Prediction 2's time effects counter this effect. A more careful analysis of the interaction of these effects in determining the power of the test is left for the next draft of this paper.

4.3.3 The Joint Distribution of the First and Second Claim Durations

So far, we have only compared marginal distributions of first and second claim times. Intuitively, much can be gained by comparing first and second claim times within contracts, that is, by studying the *joint* distribution of first and second claim times. Thus, we compare the time of the first claim T_1 and the time between the first and the second claim $T_2 - T_1$ in the subpopulation with exactly two claims in the contract year.

Assuming stationarity ($\psi \equiv 1$) and under the null of no moral hazard, we have that

$$Pr(T_1 \geq T_2 - T_1 | N(1) = 2, K \in \mathcal{K}) = \frac{1}{2}$$

for all \mathcal{K} . Under moral hazard, on the other hand, we would expect this probability to be larger than 1/2 in classes $K \leq 7$, where incentives jump down after the first claim, and smaller than 1/2 in classes $K \geq 9$, where incentives jump up. Note that here we again use that these jumps in incentives dominate the changes in incentives over time.

Thus, under stationarity ($\psi \equiv 1$), a test for moral hazard can be based on the share of contracts in classes in \mathcal{K} with two claims for which the time to the first claim is larger

than the time between the first and the second,

$$\hat{\pi}_n(\mathcal{K}) = \frac{1}{M_{2,\mathcal{K},n}} \sum_{i=1}^n I(T_{1,i} \geq T_{2,i} - T_{1,i}, N_i(1) = 2, K_i \in \mathcal{K}).$$

Another test for moral hazard under stationarity can be based on

$$\widehat{\ln \beta}_n(\mathcal{K}) = \frac{1}{M_{2,\mathcal{K},n}} \sum_{i=1}^n \ln \left(\frac{T_{1,i}}{T_{2,i} - T_{1,i}} \right) I(N_i(1) = 2, K_i \in \mathcal{K}).$$

The first two columns of Table 4 give $\hat{\pi}_n(\mathcal{K})$ and $\widehat{\ln \beta}_n(\mathcal{K})$ for various choices of \mathcal{K} . The two statistics' values, and their variation with classes, is consistent with moral hazard. The null of no moral hazard is rejected at a 5% level in the lower classes.

Precision can be increased by pooling classes at both ends of the bonus-malus scheme, but reversion the comparison for the high classes. For example, we can use

$$\hat{\pi}_n(\mathcal{K}_L, \mathcal{K}_H) = \frac{1}{M_{2,\mathcal{K}_L \cup \mathcal{K}_H, n}} \sum_{i=1}^n [I(T_{1,i} \geq T_{2,i} - T_{1,i}, N_i(1) = 2, K \in \mathcal{K}_L) + I(T_{1,i} \leq T_{2,i} - T_{1,i}, N_i(1) = 2, K \in \mathcal{K}_H)],$$

with \mathcal{K}_L and \mathcal{K}_H disjoint sets of low and high bonus-malus classes, respectively. Under moral hazard, we would expect this share to be larger than 1/2.

The first two columns of Table 5 give the values of $\hat{\pi}_n(\mathcal{K}_L, \mathcal{K}_H)$ and a similar variant $\widehat{\ln \beta}_n(\mathcal{K}_L, \mathcal{K}_H)$ of $\widehat{\ln \beta}_n(\mathcal{K})$. We expect the latter to be positive under moral hazard. The results are again consistent with moral hazard, now with some more rejections of the null at a 5% level.

Finally, [Abbring et al. \(2003\)](#) develop a variant $\hat{\pi}_n^*$ of the statistic $\hat{\pi}_n$ that allows for general external time effects ψ . Adapted to our setting, it compares the transformed durations $H_1(T_1|\mathcal{K})$ and $H_1(T_2|\mathcal{K}') - H_1(T_1|\mathcal{K})$. As before, \mathcal{K} and \mathcal{K}' can be wisely chosen to maximize power.

The third columns of Tables 4 and 5 plot the values of $\hat{\pi}_n^*$ for different bonus malus

classes, with H_1 estimated on the full sample. The results are again consistent with moral hazard.

4.3.4 The Full Sample of Claim Times

Assume that there are no external time effects, $\psi \equiv 1$, so that all nonstationarity arises from behavioral responses to variation in incentives over time. In addition, suppose that there are at most R risk-types $\lambda_1, \dots, \lambda_R$ of agents (with R reasonably small, say 10). Consider the following auxiliary model of claim rates,

$$\theta(t|\lambda, N(t-), K) = \lambda \cdot \exp[-\beta \Delta V(t, K, N(t-) + 1|\lambda)] \quad (12)$$

with $\Pr(\lambda = \lambda_r|K) = \xi_r(K)$, $r = 1, \dots, R$, and $\sum_{r=1}^R \xi_r(K) = 1$, for $K = 1, \dots, 20$, and $\Delta V(\cdot|\lambda)$ equal to $\Delta V(\cdot)$ evaluated at $p_0 = \lambda$.

Under the null of no moral hazard, $\beta = 0$ and claim rates are time-invariant. The distributions of $\lambda|K$ have the same supports $\{\lambda_1, \dots, \lambda_R\}$ across K , but with different probability masses at each support point because of sorting into classes K . Under moral hazard, we expect to find evidence that $\beta > 0$.

The auxiliary model's specification corresponds exactly to theory under the null. It can be seen as an approximation to the specification implied by theory under local alternatives to the null under a specific function form of Γ . Suppose that an agent with characteristics λ chooses p from $(0, \lambda]$, with cost function $\Gamma_\lambda(p) = (p/\tilde{\beta}) [\ln(p/\lambda) - 1]$, so that $\Gamma'_\lambda(p) = \tilde{\beta}^{-1} \ln(p/\lambda)$. Substituting in the first-order condition (6) and assuming that there is no ex post moral hazard gives

$$\begin{aligned} p^*(S) &= \lambda \cdot \exp\left(-\tilde{\beta} [V(t, W, K, N|\lambda) - V(t, W, K, N + 1|\lambda)]\right) \\ &\approx \lambda \cdot \exp\left[-\tilde{\beta} e^{-\alpha\rho W} \Delta V(t, K, N + 1|\lambda)\right], \end{aligned}$$

where the approximation in the second line holds near the null of no moral hazard. Thus,

the auxiliary model (12) is a good approximation to the optimal claiming hazard near the null, that is, for small $\tilde{\beta}$, with $\beta = \tilde{\beta}e^{-\alpha\rho W}$. The intuition for a test based on an estimate of β in (12) does not rest on this specific approximation and functional form, though, and we expect such a test to have power against moral hazard more generally.

We estimate the auxiliary model with parametric maximum likelihood. We first estimate it on the full sample of contract years, imposing the restrictions across classes inherent in the auxiliary model and computing ΔV using the linear specification ($\alpha = 0$). As a robustness check, we also estimate the model separately on the 20 subsamples corresponding to each of the classes K . This implicitly allows β and the support of λ to vary between classes. Finally, we investigate robustness by repeating the estimates for a specification with risk aversion, $\alpha = 0.3$.

The likelihood can be computed using a discrete (daily) approximation, building on

$$\Pr(N(t+1/365-) - N(t-) = 1 | \lambda, N(t-), K) = \frac{\theta(t|\lambda, N(t-), K)}{365}, \quad t \in \{0, 1/365, \dots, 364/365\}.$$

Each likelihood computation embeds the algorithm in Appendix B to compute $\Delta V(\cdot | \lambda_r)$ (that is, $\Delta V(\cdot)$ at $p_0 = \lambda_r$), $r = 1, \dots, R$, at daily times. Wald and/or likelihood-ratio tests can be used to test for $\beta = 0$ against the alternative $\beta > 0$.

Results will be included in a next draft.

4.4 Claim Sizes

As discussed in Section 4.2, the jumps in incentives at the time of a claim dominate the variation in incentives over time. Therefore, in comparing claim sizes within a contract year, we can focus on Prediction 3's occurrence-dependence effects, and ignore Prediction 2's time effects.

This facilitates a test for ex post moral hazard based on a comparison of the sizes of agents' first and second claims in a contract year, even though these occur at different

times. Under ex post moral hazard the size L_2 of a second claim in a contract year is stochastically larger than the size L_1 of a first claim in the classes $K \geq 9$ where incentives jump up after the first claim. First claim sizes are stochastically larger in classes $K \leq 7$.

Under the null of no moral hazard, first and second claim sizes share the same distribution $F(\cdot|\lambda)$. Table 6 reports p -values of Wilcoxon and sign tests for this hypothesis against one-sided and two-sided alternatives, using subsamples of contracts with two claims and in different bonus-malus classes.¹⁶ There is evidence that L_1 and L_2 are not identically distributed. This is due to the second claim being stochastically larger in the subpopulation in classes $K \geq 9$. This is consistent with ex post moral hazard: Agents in classes $K \geq 9$ increase their claiming thresholds x^* after experiencing a jump up in their incentives at the time of their first claim.

4.5 Claim Withdrawals

Suppose that it takes time for loss amounts to be assessed, so that agents have to file a claim before the loss amount is fully known. Furthermore, suppose that there are no (costs— administrative or informational— of filing and withdrawing claims. Then, agents will report all losses to the insurer to secure an option on compensation, and typically withdraw those claims for losses that fall below the threshold. Our data on claims and withdrawals are thus directly informative on ex post moral hazard (withdrawals), and ex ante moral hazard (initial claims). If we relax our assumptions, some ex post moral hazard will end up reducing initial claims, but we can still test for ex ante and ex post moral hazard. This is left for this paper’s next draft.

¹⁶The results do not change much if we include contracts with more than two claims.

5 Conclusion

Putting novel theoretical insights into the dynamic incentives implied by experience rating to empirical use, we find some traces of moral hazard in Dutch car insurance. The earlier literature, including our related work for France ([Abbring et al., 2003](#)), often fails to find such evidence. Our empirical analysis will benefit from further analysis of the way the time and state-dependence effects implied by theory interact in determining our tests' power. Also, our separate results on ex ante and ex post moral hazard await integration. This is left for this paper's next draft.

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Appendices

A Proofs of Results in Section 3

Lemma 1. *The value function V is strictly increasing in wealth W .*

Proof. Consider a state (t, W, K, N) and denote the (stochastic) optimal consumption-prevention-claim plan following this state by $(c^*, p^*, \mathcal{X}^*)$. Then, in state (t, W', K, N) with $W' > W$, the agent can attain an expected discounted utility equal to $V(t, W, K, N)$ by following the same plan $(c^*, p^*, \mathcal{X}^*)$. Because consuming $c^* + \rho(W' - W) > c^*$ is feasible and instantaneous utility u is strictly increasing, $V(t, W', K, N) > V(t, W, K, N)$. \square

Lemma 2. *The value function V is weakly increasing in the bonus-malus class K and weakly decreasing in the number of claims at fault N .*

Proof. Consider a state (t, W, K, N) and denote the (stochastic) optimal consumption-prevention-claim plan following this state by $(c^*, p^*, \mathcal{X}^*)$. Then, in state (t, W, K', N') with $K' \geq K$ and $N' \leq N$, the agent can attain an expected discounted utility equal to $V(t, W, K, N)$ by following the same plan $(c^*, p^*, \mathcal{X}^*)$. In this case future insurance premia are weakly smaller, in the sense of stochastic dominance, than under optimal behavior in state (t, W, K, N) , because $B(K, N)$ is weakly increasing in K and weakly decreasing in N , premia are decreasing in K , and the agent faces the same distribution of future claims. Therefore, choosing $(c^*, p^*, \mathcal{X}^*)$ in state (t, W, K, N) is feasible and, indeed, $V(t, W, K', N') \geq V(t, W, K, N)$. \square

Proof of Proposition 2 (sketch). First, note that the proposition's specifications of the consumption rule and value function satisfy the Euler equation:

$$u'(c^*(S)) = e^{-\alpha\rho[W-Q(t,K,N)]} = V_W(S)$$

Second, note that $\rho V(S) = u(c^*(S))$, so that Bellman equation (3) is satisfied if

$$0 = p_0 \left[V(t, W, K, N + 1) - V(S) \right] + V_W(S) [\rho W - c^*(S) - \pi(K)] + V_t(S).$$

Because

$$V(t, W, K, N + 1) - V(S) = e^{-\alpha\rho[W - Q(t, K, N)]} \left(\frac{1 - e^{\alpha\rho[Q(t, K, N+1) - Q(t, K, N)]}}{\alpha\rho} \right),$$

$$V_W(S) [\rho W - c^*(S) - \pi(K)] = e^{-\alpha\rho[W - Q(t, K, N)]} [\rho Q(t, K, N) - \pi(K)], \text{ and}$$

$$V_t(S) = -e^{-\alpha\rho[W - Q(t, K, N)]} Q_t(t, K, N),$$

this is guaranteed by equation (8). Third, the Bellman equation's premium renewal conditions (2) are satisfied by equation (9):

$$\begin{aligned} V(1, W, K, N) &= \frac{1 - e^{-\alpha\rho[W - Q(1, K, N)]}}{\alpha\rho} \\ &= \frac{1 - e^{-\alpha\rho[W - Q(0, B(K, N), 0)]}}{\alpha\rho} = V(0, W, B(K, N), 0). \end{aligned}$$

Finally, using standard methods it can be proved that there exists a unique solution Q to the system (8)–(9). \square

B Computation of Proposition 2's Function Q

Let B and π be given by Table 1 and attach some values to the parameters ρ , α , and p_0 .

In the limiting case $\alpha \downarrow 0$, the corresponding initial-value problem (8)–(9) has an explicit analytical solution Q . In particular, the initial values $Q(0, \cdot, 0)$ can be computed

directly using

$$\begin{pmatrix} Q(0, 1, 0) \\ \vdots \\ Q(0, 20, 0) \end{pmatrix} = \frac{1 - e^{-\rho}}{\rho} (I - e^{-\rho}T)^{-1} \begin{pmatrix} \pi(1) \\ \vdots \\ \pi(20) \end{pmatrix}. \quad (13)$$

Here, I is the 20×20 identity matrix and T is the annual transition probability matrix among bonus-malus classes implied by p_0 and B . The solution Q then satisfies the recursive system

$$\begin{aligned} Q(t, K, N) &= \frac{\pi(K)}{\rho} + e^{-\rho(1-t)} \left[Q(0, 1, 0) - \frac{\pi(K)}{\rho} \right] \quad \text{for } N \geq 3, \\ Q(t, K, 2) &= Q(t, K, 3) + e^{-(\lambda+\rho)(1-t)} [Q(0, B(K, 2), 0) - Q(0, 1, 0)], \\ Q(t, K, 1) &= Q(t, K, 2) + e^{-(\lambda+\rho)(1-t)} \{Q(0, B(K, 1), 0) - Q(0, B(K, 2), 0) \\ &\quad + \lambda(1-t)[Q(0, B(K, 2), 0) - Q(0, 1, 0)]\}, \text{ and} \\ Q(t, K, 0) &= Q(t, K, 1) + e^{-(\lambda+\rho)(1-t)} \{Q(0, B(K, 0), 0) - Q(0, B(K, 1), 0) \\ &\quad + \lambda(1-t)[Q(0, B(K, 1), 0) - Q(0, B(K, 2), 0)] \\ &\quad + \frac{1}{2}\lambda^2(1-t)^2[Q(0, B(K, 2), 0) - Q(0, 1, 0)]\}. \end{aligned}$$

In the general case, the function Q can be computed iteratively using

Algorithm 1. Give starting values to $Q(0, K, 0)$, $K = 1, \dots, 20$, and repeat

1. set $Q^*(0, K, 0) = Q(0, K, 0)$, $K = 1, \dots, 20$;

2. for $K = 1, \dots, 20$,

(a) for $N \geq 3$, set

$$Q(t, K, N) = \frac{\pi(K)}{\rho} + e^{-\rho(1-t)} \left[Q(0, 1, 0) - \frac{\pi(K)}{\rho} \right];$$

(b) for $N = 2, 1, 0$, set $Q(\cdot, K, N)$ to the numerical solution of the corresponding

single-equation initial-value problem in (8)–(9);

until $\max_K |Q(0, K, 0) - Q^(0, K, 0)| \leq \varepsilon$, for some small $\varepsilon > 0$.*

The values $Q(0, \cdot, 0)$ for the linear-utility case, that is that satisfy (13), can be used as starting values in Algorithm 1. Note that in the linear-utility case itself, this produces Q in one iteration; in cases with $\alpha > 0$, more iterations are typically needed. If we have to compute Q for multiple values of α , we can use the linear-utility values of $Q(0, \cdot, 0)$ as starting values for the computations with the lowest value of α , the resulting $Q(0, \cdot, 0)$ as starting values for the computations with the second-lowest value of α , etcetera.

C Data

[To be edited]

Figure 1: Shares of Contracts with At Least One and Two Claims at Fault by Bonus-Malus Class

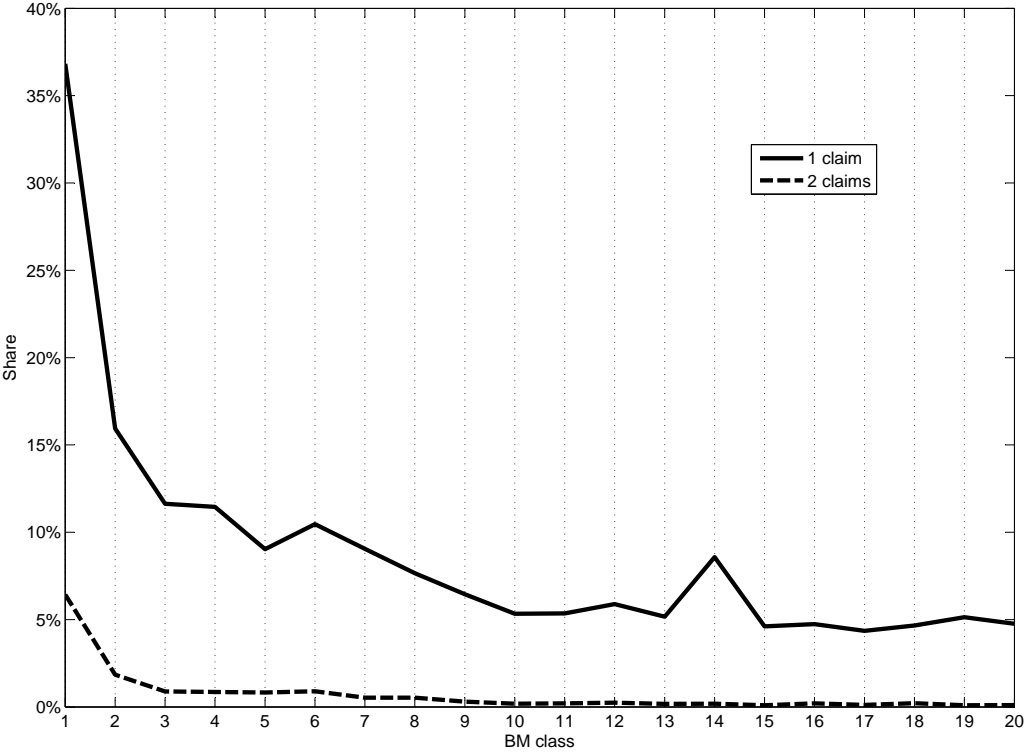
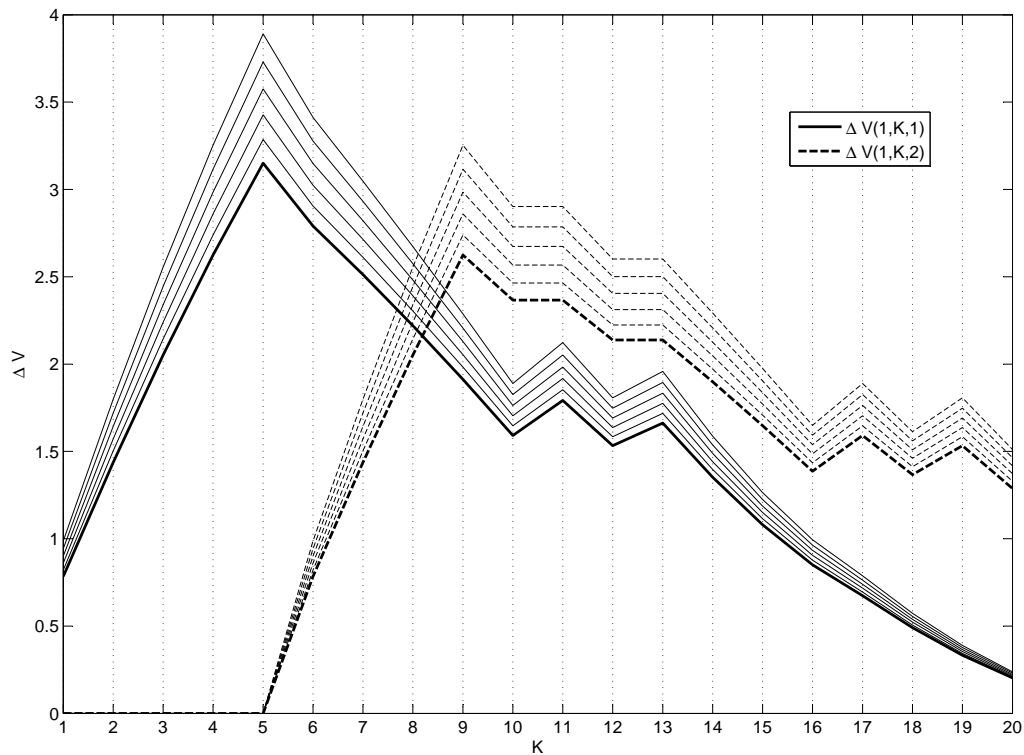
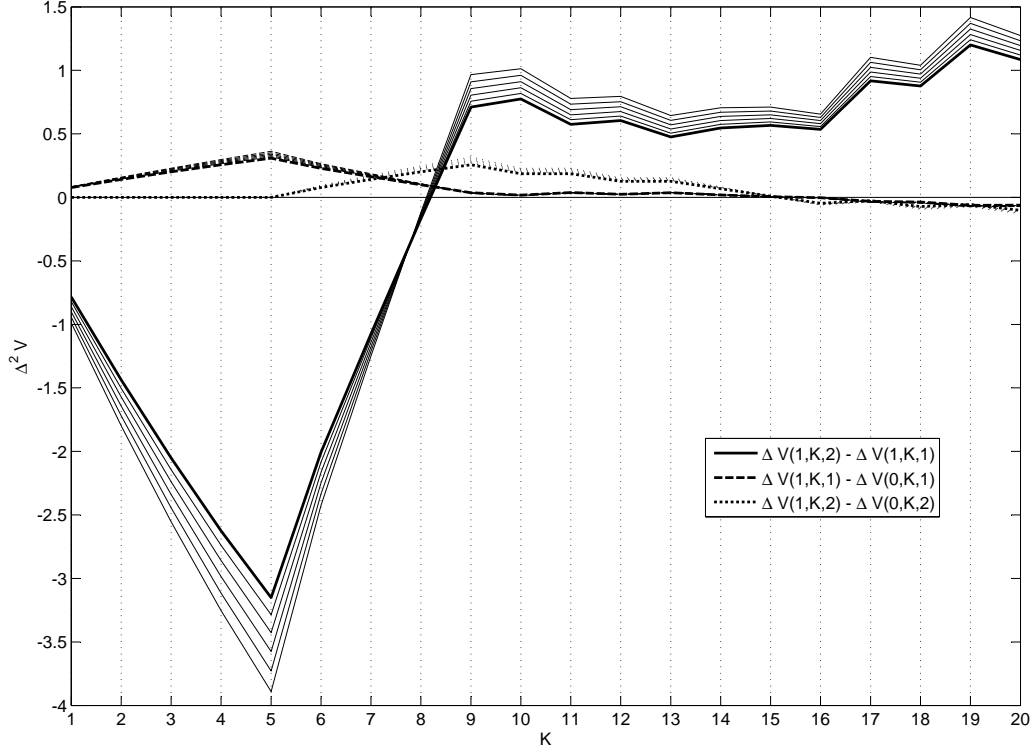


Figure 2: Incentives to Avoid First and Second Claims; at an Average Risk Level



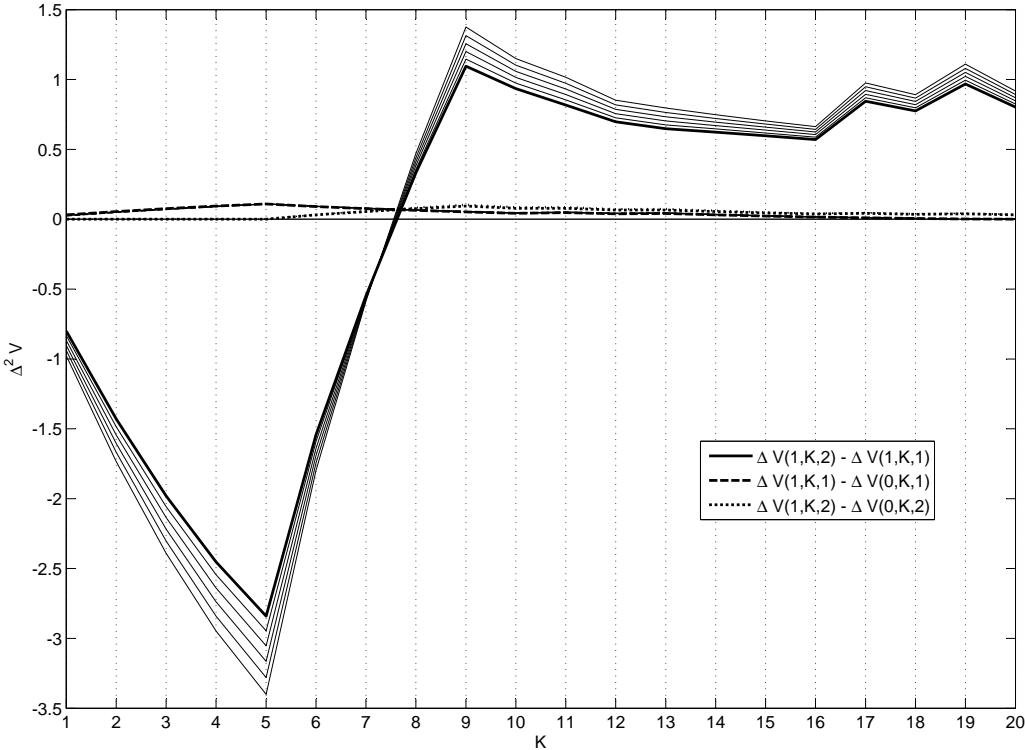
Note: This figure plots $\Delta V(1, K, 1)$ and $\Delta V(1, K, 2)$ as functions of K for the CARA case without moral hazard, for $p_0 = 0.064$ and different values of the coefficient of absolute risk aversion α . The premium $\pi(K)$ is measured in multiples of the base premium, as in Table 1. The bold graphs correspond to the linear-utility case $\alpha = 0$ and give the expected discounted premium cost of a claim in terms of the base premium. The other graphs correspond to $\alpha = 0.1, 0.2, \dots, 0.5$, in that order and with the graphs corresponding to $\alpha = 0.1$ closest to the bold graph. At a consumption level equal to 20 times the base premium, $\alpha = 0, 0.1, \dots, 0.5$ correspond to coefficients of *relative* risk aversion equal to $0, 2, \dots, 10$, respectively.

Figure 3: Change in Incentives to Avoid a Claim after the First Claim, and Changes in Incentives to Avoid a First and a Second Claim over the Course of a Contract Year; at an Average Risk Level



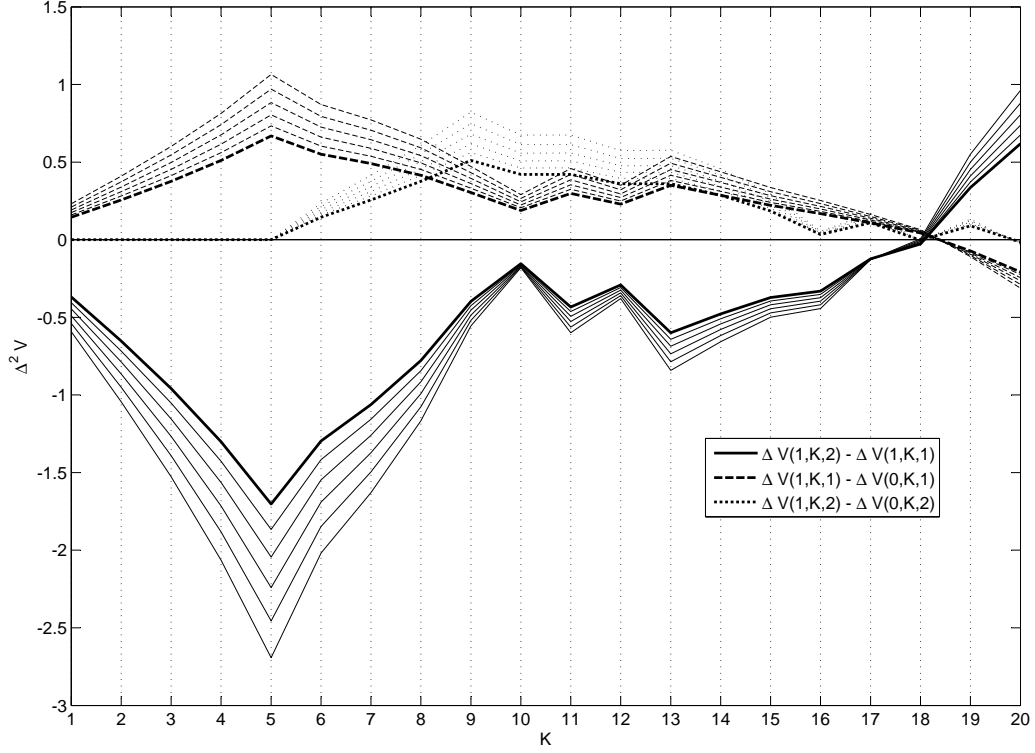
Note: This figure plots $\Delta V(1, K, 2) - \Delta V(1, K, 1)$, $\Delta V(1, K, 1) - \Delta V(0, K, 1)$, and $\Delta V(1, K, 2) - \Delta V(0, K, 2)$ as functions of K for the CARA case without moral hazard, for $p_0 = 0.064$ and different values of the coefficient of absolute risk aversion α . The premium $\pi(K)$ is measured in multiples of the base premium, as in Table 1. The bold graphs correspond to the linear-utility case $\alpha = 0$ and give the expected discounted premium cost of a claim in terms of the base premium. The other graphs correspond to $\alpha = 0.1, 0.2, \dots, 0.5$, in that order and with the graphs corresponding to $\alpha = 0.1$ closest to the bold graph. At a consumption level equal to 20 times the base premium, $\alpha = 0, 0.1, \dots, 0.5$ correspond to coefficients of *relative* risk aversion equal to 0, 2, \dots , 10, respectively.

Figure 4: Change in Incentives to Avoid a Claim after the First Claim; and Changes in Incentives to Avoid a First and a Second Claim over the Course of a Contract Year; at a Zero Risk Level



Note: This figure plots $\Delta V(1, K, 2) - \Delta V(1, K, 1)$, $\Delta V(1, K, 1) - \Delta V(0, K, 1)$, and $\Delta V(1, K, 2) - \Delta V(0, K, 2)$ as functions of K for the CARA case without moral hazard, for $p_0 = 0$ and different values of the coefficient of absolute risk aversion α . The premium $\pi(K)$ is measured in multiples of the base premium, as in Table 1. The bold graphs correspond to the linear-utility case $\alpha = 0$ and give the expected discounted premium cost of a claim in terms of the base premium. The other graphs correspond to $\alpha = 0.1, 0.2, \dots, 0.5$, in that order and with the graphs corresponding to $\alpha = 0.1$ closest to the bold graph. At a consumption level equal to 20 times the base premium, $\alpha = 0, 0.1, \dots, 0.5$ correspond to coefficients of *relative* risk aversion equal to $0, 2, \dots, 10$, respectively.

Figure 5: Change in Incentives to Avoid a Claim after the First Claim; and Changes in Incentives to Avoid a First and a Second Claim over the Course of a Contract Year; at a High Risk Level



Note: This figure plots $\Delta V(1, K, 2) - \Delta V(1, K, 1)$, $\Delta V(1, K, 1) - \Delta V(0, K, 1)$, and $\Delta V(1, K, 2) - \Delta V(0, K, 2)$ as functions of K for the CARA case without moral hazard, for $p_0 = 0.4592$ and different values of the coefficient of absolute risk aversion α . The premium $\pi(K)$ is measured in multiples of the base premium, as in Table 1. The bold graphs correspond to the linear-utility case $\alpha = 0$ and give the expected discounted premium cost of a claim in terms of the base premium. The other graphs correspond to $\alpha = 0.1, 0.2, \dots, 0.5$, in that order and with the graphs corresponding to $\alpha = 0.1$ closest to the bold graph. At a consumption level equal to 20 times the base premium, $\alpha = 0, 0.1, \dots, 0.5$ correspond to coefficients of *relative* risk aversion equal to 0, 2, \dots , 10, respectively.

Figure 6: Comparison of \hat{H}_1 with the Uniform Distribution for Low and High Bonus-Malus Classes

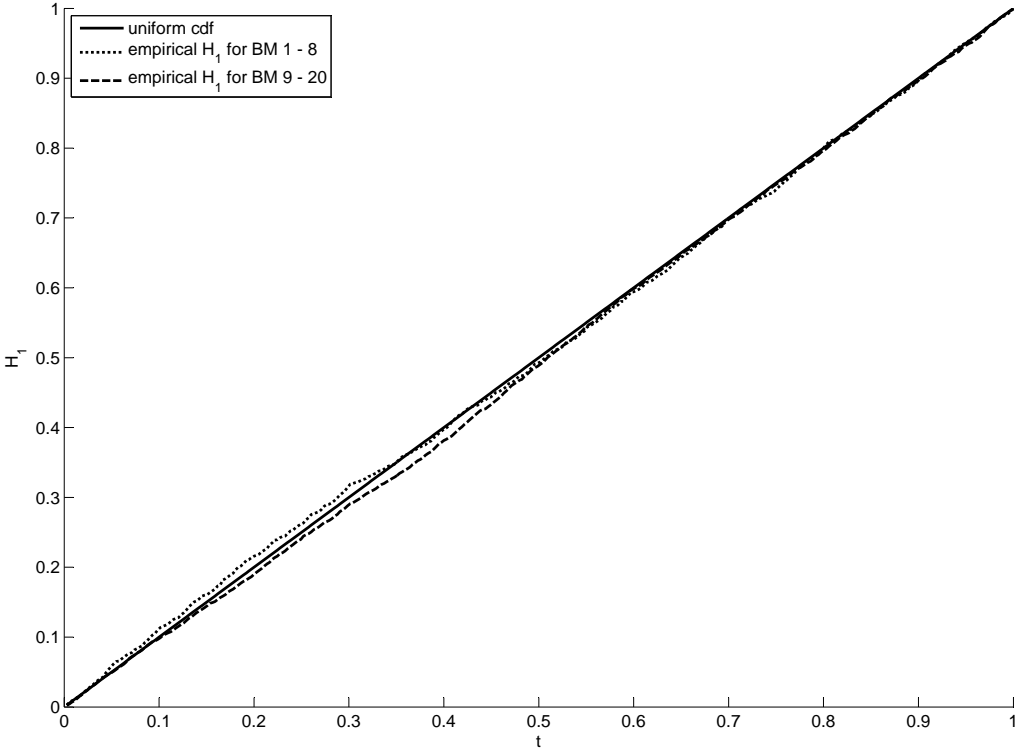


Figure 7: Comparison of \hat{H}_1 with the Uniform Distribution and of \hat{H}_1^2 with \hat{H}_2 for Low and High Bonus-Malus Classes, with \hat{H}_1 and \hat{H}_2 Estimated on the Same Classes

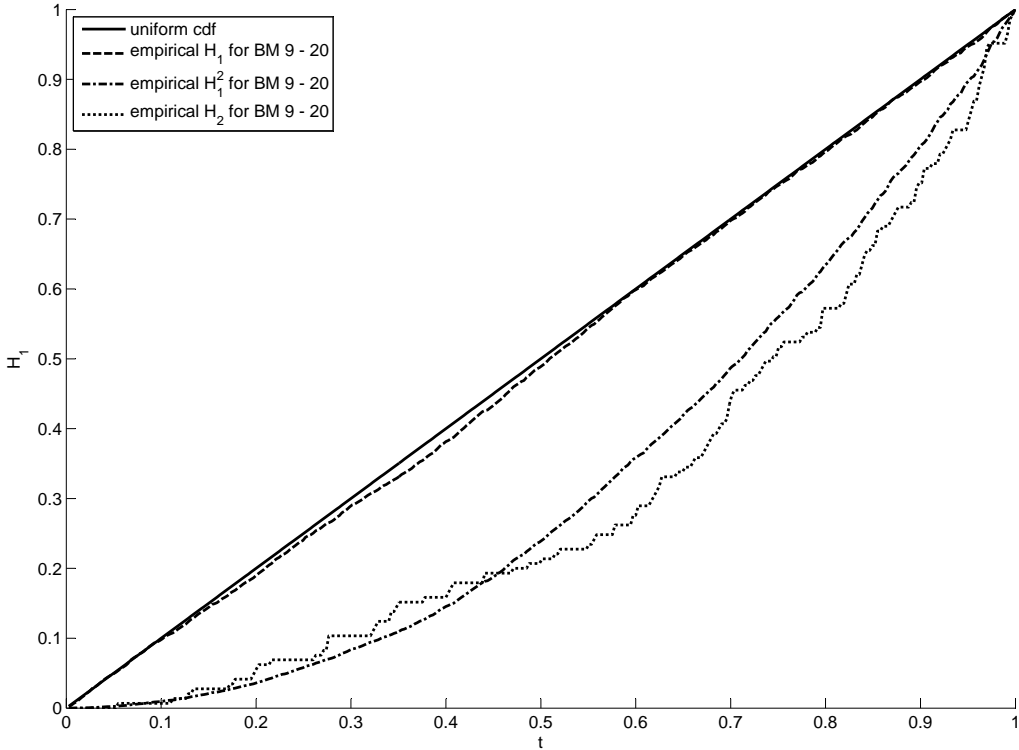
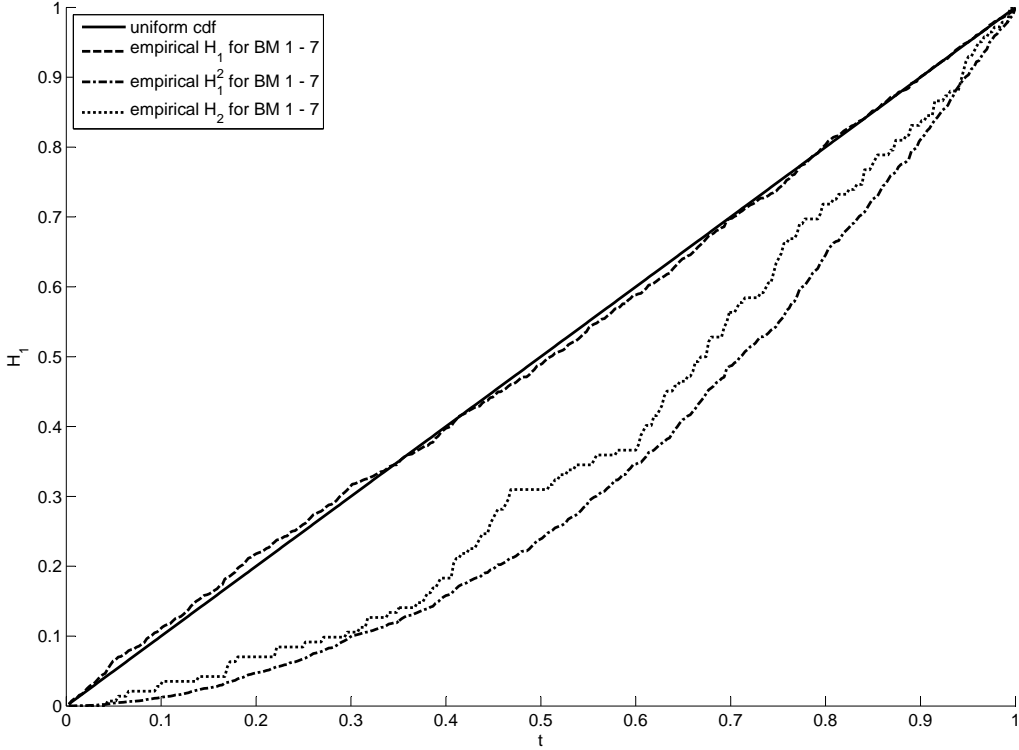


Figure 8: Comparison of \hat{H}_1 with t and \hat{H}_1^2 with \hat{H}_2 for Low and High Bonus-Malus Classes, with \hat{H}_1 and \hat{H}_2 Estimated on Different Classes

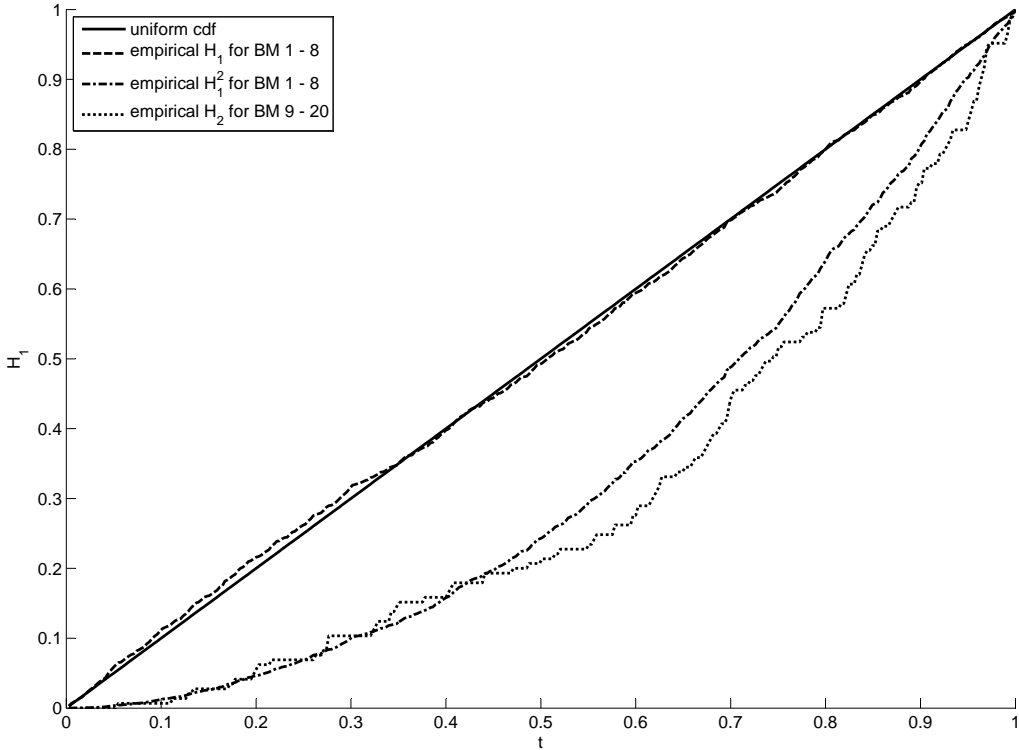
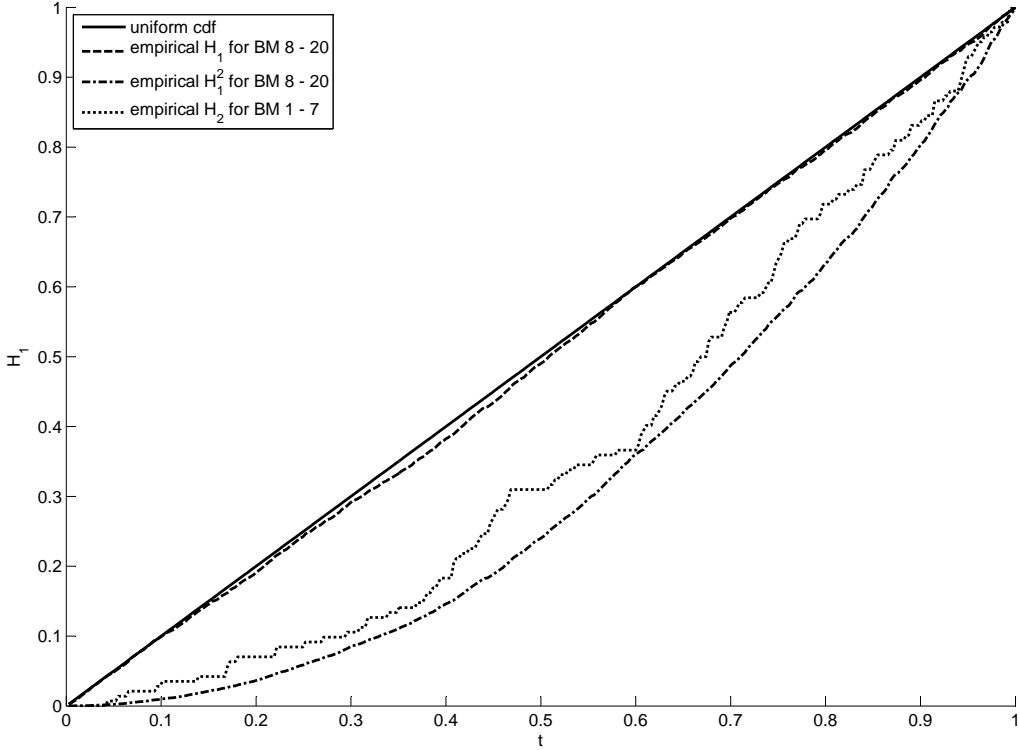


Table 1: Bonus-Malus Scheme

Present BM class	Premium paid	Future BM class after one contract year with			
		no claim	1 claim	2 claims	3 or more claims
20	25%	20	14	8	1
19	25%	20	13	7	1
18	25%	19	12	7	1
17	25%	18	11	6	1
16	25%	17	10	6	1
15	25%	16	9	5	1
14	25%	15	8	4	1
13	30%	14	7	3	1
12	35%	13	7	3	1
11	37.5%	12	6	2	1
10	40%	11	6	2	1
9	45%	10	5	1	1
8	50%	9	4	1	1
7	55%	8	3	1	1
6	60%	7	2	1	1
5	70%	6	1	1	1
4	80%	5	1	1	1
3	90%	4	1	1	1
2	100%	3	1	1	1
1	120%	2	1	1	1

Table 2: Percentage Premium Change after a Claim-Free Contract Year and Marginal Percentage Changes in the Premium after each Claim, by Bonus-Malus Class

Present BM class	Premium change no claim	Increase in premium after		
		1st claim	2nd claim	3rd claim
20	0%	0%	100%	140%
19	0%	20%	83%	118%
18	0%	40%	57%	118%
17	0%	50%	60%	100%
16	0%	60%	50%	100%
15	0%	80%	56%	71%
14	0%	100%	60%	50%
13	-17%	120%	64%	33%
12	-14%	83%	64%	33%
11	-7%	71%	67%	20%
10	-6%	60%	67%	20%
9	-11%	75%	71%	0%
8	-10%	78%	50%	0%
7	-9%	80%	33%	0%
6	-8%	82%	20%	0%
5	-14%	100%	0%	0%
4	-13%	71%	0%	0%
3	-11%	50%	0%	0%
2	-10%	33%	0%	0%
1	-17%	20%	0%	0%

Note: The second column reports

$$\frac{\text{New premium after claim-free year} - \text{Old premium}}{\text{Old premium}}$$

for each bonus malus class. The third, fourth and fifth columns report

$$\frac{\text{New premium after year with } N \text{ claims} - \text{New premium after year with } N - 1 \text{ claims}}{\text{New premium after year with } N - 1 \text{ claims}}$$

for respectively $N = 1, 2, 3$, for all bonus-malus classes.

Table 3: Numbers of Contracts and Claims (at fault) by Bonus-Malus Class

BM class	Number of contracts with					Total
	no claim	1 claim	2 claims	3 claims	4 claims	
1	501	241	44	6	1	793
2	775	130	16	1		922
3	995	121	10			1,126
4	1,345	161	13			1,519
5	1,863	168	16	1		2,048
6	2,515	269	23	2		2,809
7	3,456	324	20			3,800
8	4,355	336	25			4,716
9	4,988	328	14	2		5,332
10	6,623	360	12		1	6,996
11	6,185	337	11	2		6,535
12	6,120	367	16			6,503
13	5,600	295	10			5,905
14	6,548	601	13			7,162
15	6,309	299	6			6,614
16	6,513	310	13	1		6,837
17	5,825	258	7			6,090
18	4,458	208	10			4,676
19	3,971	211	4			4,186
20	28,045	1,372	29	2		29,448
Total	106,990	6,696	312	17	2	114,017

Table 4: Tests Based on a Comparison of First and Second Claim Durations, for Different Bonus-Malus Classes

BM class	Test statistics (std. error)		
	$\hat{\pi}_n$	$\widehat{\ln \beta}_n$	$\hat{\pi}_n^*$
1	65.9% (7.5%)	0.571 (0.273)	63.6% (7.6%)
1-2	65.0% (6.5%)	0.477 (0.234)	63.3% (6.5%)
1-3	62.9% (6.0%)	0.419 (0.217)	61.4% (6.0%)
1-4	59.0% (5.5%)	0.364 (0.199)	57.8% (5.5%)
1-5	57.6% (5.0%)	0.294 (0.182)	56.6% (5.0%)
1-6	54.1% (4.5%)	0.128 (0.164)	52.5% (4.6%)
1-7	53.5% (4.2%)	0.148 (0.152)	52.1% (4.2%)
9-20	51.0% (4.2%)	0.091 (0.151)	50.3% (4.2%)
10-20	51.9% (4.4%)	0.105 (0.158)	51.9% (4.4%)
12-20	50.9% (4.8%)	0.033 (0.175)	50.9% (4.8%)
14-20	51.2% (5.5%)	0.090 (0.200)	51.2% (5.5%)
16-20	47.6% (6.3%)	-0.053 (0.229)	46.0% (6.3%)
18-20	46.5% (7.6%)	-0.126 (0.277)	44.2% (7.6%)
19-20	42.4% (8.7%)	-0.082 (0.316)	39.4% (8.7%)
20	41.4% (9.3%)	-0.112 (0.337)	41.4% (9.3%)

Note: The values in **bold** imply rejection of the null of no moral hazard at a 5% level. In the computation of $\hat{\pi}_n^*$, H_1 was estimated using all bonus-malus classes.

Table 5: Tests Based on a Comparison of First and Second Claim Durations that Pool Low and High Bonus-Malus Classes

BM classes		Test statistics (std. error)		
low	high	$\hat{\pi}_n$	$\widehat{\ln \beta_n}$	$\hat{\pi}_n^*$
1	20	63.0% (5.9%)	0.389 (0.212)	61.6% (5.9%)
1	19–20	62.3% (5.7%)	0.361 (0.207)	62.3% (5.7%)
1–2	20	62.9% (5.3%)	0.358 (0.192)	61.8% (5.3%)
1–2	19–20	62.4% (5.2%)	0.337 (0.188)	62.4% (5.2%)
1–2	18–20	60.2% (4.9%)	0.331 (0.179)	60.2% (5.0%)
1–2	17–20	60.9% (4.8%)	0.354 (0.173)	60.9% (4.8%)
1–3	17–20	60.0% (4.6%)	0.331 (0.166)	60.0% (4.6%)
1–3	16–20	57.9% (4.3%)	0.246 (0.157)	57.9% (4.4%)
1–4	16–20	56.2% (4.1%)	0.230 (0.150)	56.2% (4.2%)
1–5	15–20	54.2% (3.9%)	0.136 (0.140)	54.2% (3.9%)
1–6	13–20	52.3% (3.4%)	0.056 (0.124)	51.4% (3.5%)
1–7	11–20	51.7% (3.1%)	0.047 (0.112)	51.0% (3.1%)
1–7	9–20	51.2% (3.0%)	0.027 (0.107)	50.9% (3.0%)

Note: The values in **bold** imply rejection of the null of no moral hazard at a 5% level. In the computation of $\hat{\pi}_n^*$, H_1 was estimated using all bonus-malus classes.

Table 6: Comparison of First and Second Claim Sizes for Various Bonus-Malus Classes

BM classes	# obs.	Wilcoxon test <i>p</i> -value	<i>p</i> -value of Sign test $H_0 : L_1 \sim L_2$ vs.		
			$L_1 \succ L_2$	$L_1 \prec L_2$	$L_1 \not\sim L_2$
All	312	0.0241	0.9981	0.0027	0.0055
1 – 7	142	0.2198	0.9233	0.1040	0.2080
8	25	0.5098	0.9461	0.1148	0.2295
9 – 20	145	0.0829	0.9901	0.0152	0.0305