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THE IMPORTANCE OF THE CHOICE OF TEST FOR FINDING EVIDENCE OF ASYMMETRIC INFORMATION

BY

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ABSTRACT

We put one of the predictions of adverse-selection models to the test, using data from the Danish automobile insurance market: that there is a positive correlation between claims risk and insurance coverage. We can find a statistically significant insurance coverage–risk correlation when coverage is expressed relative to the insurance premium, but not when it is expressed in monetary terms.

KEYWORDS

Adverse selection, moral hazard, automobile insurance, learning, bivariate probit.

1. INTRODUCTION

Asymmetric information is present almost everywhere in insurance. Policyholders are privy to information about themselves, which affects their risk of making a claim to the insurer. For example, automobile drivers may know if they are aggressive or calm while driving. The insurer may believe that such latent information is correlated with the accident risk of the driver, but is unlikely to be able to observe it. If the accident risk of the driver is not perfectly observable, the insurer is at an informational disadvantage to the driver, which means that asymmetric information is present.

We test for existence of asymmetric information by examining the relationship between the policyholder's claims risk and level of insurance coverage, using data from the Danish automobile insurance market. If either an individual with a high claims risk chooses more insurance coverage or the mere fact of having insurance coverage modifies the claims risk of an individual, then we might expect to find a positive correlation between the policyholder's claims risk and level of insurance coverage (Chiappori and Salanié, 2000).

We find that the choice of statistical test is critical when analysing the correlation between risk and the insurance coverage bought by the policyholder. For

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example, we can find a statistically significant risk–coverage correlation when coverage is expressed relative to the insurance premium, but not when it is expressed in monetary terms. Our conclusion is that the results are not robust: they depend on the test chosen for the analysis.

The two special cases of asymmetric information that may cause the positive correlation property are adverse selection and moral hazard. Adverse selection refers to a market process in which poor products or customers are more likely to be selected, due to asymmetric information. The asymmetry can be caused by private information of one of the parties. It can be due to regulations or social norms that prevent the insurer from using certain characteristics to set the premiums. Two ways to model adverse selection are with signalling games and screening games; see Spence (1973).

Moral hazard means that the policyholder may have some degree of control over the probability and size of the occurrence of an insured event, due to the care taken. Care can be interpreted not only as money, but also as diligence, mental concentration or intensity of effort; see Ehrlich and Becker (1972).

Under adverse selection without moral hazard, the degree of insurance coverage chosen by the policyholder is based on the ex ante assessment that a policyholder makes of their likelihood of having an accident. Neither the frequency nor the claim size are functions of the actions of the policyholder since moral hazard does not exist.

In the presence of moral hazard, the amount of insurance coverage affects the efforts of the policyholder to prevent accidents. The probability of an accident can be seen as a function of the level of care taken, which is unobservable by the insurer. Generous coverage reduces the expected cost of an accident for the policyholder and therefore the incentives for safety. More coverage may lead to more accidents.

Moral hazard can be subdivided into two types. Ex ante moral hazard occurs before an accident. It concerns the impact of the policyholder's actions on the probability of occurrence and severity upon occurrence of the insured event. For example, the policyholder would demonstrate ex ante moral hazard if they smoked in bed only after the purchase of fire insurance. Ex post moral hazard occurs during or after an accident, and affects the severity of the claim. For example, the policyholder would demonstrate ex post moral hazard if they did not pick up their wallet as they escaped from their burning house, which they would have done if they had not been covered by the fire insurance policy. Similarly, by claiming on their fire insurance policy for a personal possession destroyed by the fire, for an item that the policyholder would not have replaced if they were not covered by insurance, the policyholder also demonstrates ex post moral hazard. See Chiappori and Salanié (2013) for a further discussion of the distinction between these two types of moral hazard.

Each of moral hazard and adverse selection predict that, conditional on the underwriting variables used for pricing the insurance policy, there should be a positive correlation between risk and coverage both within a risk class across consecutive time periods and within a single time period. An empirically observed positive correlation may be due to the omission of some information in the analysis. For example, a risk characteristic of the policyholder that is not used by the insurer in pricing may lead to a spurious positive correlation (Chiappori and Salanié, 2013). Nevertheless, conditional on the underwriting variables used for pricing the insurance policy, the correlation between coverage and risk should be a good test for asymmetric information since policyholders who choose different levels of insurance coverage should be different in either their risk aversion or their risk preferences (or both).

While evidence of a coverage–risk correlation is found in studies of some insurance markets,[1] the findings have been rather diverse in the automobile insurance market. Three initial studies, Dahlby (1983, 1992); Puelz and Snow (1994), suggest the existence of a coverage–risk correlation. Their findings were challenged by the research of Chiappori and Salanié (2000) and Dionne *et al.* (2001). Chiappori and Salanié use more refined methods and cannot reject a zero correlation between higher insurance coverage and more accidents in their French data.[2] Nor can Dionne *et al.* find evidence for asymmetric information using data from Quebec, and the same goes for Saito (2006) on the Japanese automobile insurance market. Cohen (2005) finds a positive coverage–risk correlation in the Israeli automobile insurance market.

These scattered conclusions might be due to a number of reasons. For example, there may be differences in the specific data sets, the definition of claim, the statistical tests chosen or the market structures. For instance, Kim *et al.* (2009) find evidence of asymmetric information in the automobile insurance market of Korea, using a multinomial measurement but not with the more traditional dichotomous measurement. There is also empirical evidence that risk-averse policyholders tend to buy more coverage and yet be more cautious, hence they are less risky; see de Meza and Webb (2001). Sonnenholzner and Wambach (2009) find that patient policyholders use high effort to avoid a loss and buy high insurance coverage, whereas the impatient ones do not. This may counter the effects of adverse selection.

We test if the scattered conclusions might be due to the choice of statistical test. The tests used in the literature define high coverage as high relative either to the insurance premium (Cohen, 2005) or to a chosen monetary level (Dionne *et al.*, 2001; Saito, 2006), or use a definition that does not make such distinctions (for example, Chiappori and Salanié (2000) define coverage as high if it is complete — i.e. comprehensive — insurance coverage rather than partial insurance[3]). We apply both possible definitions of relative high coverage, in separate tests and on the same data. We use a rich data set from the Danish automobile insurance market. We have access to all data available to the insurer who supplied the data. This is important since we can use the same pricing scheme as the insurer, and avoid spurious effects due to under- or over-parameterisation. We focus on the coverage of property damages (called collision coverage in some countries) since it is the only coverage of the automobile insurance product for which the policyholder chooses the level of deductible. The lower the deductible chosen by the policyholder, the higher the amount of coverage, and vice versa.

In the absence of any information on policyholders' risk aversion, we assume that they have the same level of risk aversion. Then each policyholder is fully described by a single number, for example their individual probability of accident. It follows that the policyholders who have a high propensity of experiencing accidents will choose a higher coverage than those with a low propensity. Note that the policyholder's level of risk aversion can cause the opposite effect.

We find that for fixed-price product policyholders, the results are not robust to the choice of test. It matters how the insurance coverage is expressed, whether relative to the premium paid or in absolute monetary terms. It matters at what level the coverage is deemed to be high. For the same data subset, a statistically significant positive correlation is found only when a high coverage is defined as the policyholder's chosen deductible equalling three times their premium or more. Our findings are consistent with the previous literature, and may account for some of the disparities between them. However, we do not have an explanation for why it should matter how the insurance coverage is expressed. This is very interesting, and it requires further investigation.

Analogous to the study of Cohen (2005), we also investigate the policyholders who are new to the insurer. New policyholders are more likely to have an advantage in terms of the amount of information over the insurer. It may also be the case that an insurer is better able to evaluate the information that they have collected on repeat policyholders than the policyholders themselves. We are able to find a statistically significant positive correlation between risk and the level of coverage for new policyholders who have bought a fixed-price product.

The paper is arranged as follows: in Section 2, we present the economic model of asymmetric information and motivate the tests for asymmetric information. In Section 3, we describe the data and the products offered by the insurer. The results are presented and discussed in Section 4. We conclude in Section 5.

2. Are tests for asymmetric information robust?

We consider a market in which the insurer makes an exclusive contract with the policyholder. For example, a policyholder can not have more than one automobile insurance policy for each car, due to possible moral hazard. It allows insurers to implement non-linear and, in particular, convex pricing schemes, which are typically needed under asymmetric information; see Chiappori (2000) and Frees *et al.* (2009).

The policies offered by the insurer, as for all policies offered in the Danish automobile market, are one-period policies with no commitment on the part of either the insurer or the policyholder. This means that a policyholder can switch to another insurance company in the next period if they wish. In the Danish market, insurers do not share information about their policyholders with other insurers. Despite the inability to commit, both parties can sign a first-period contract that should be followed by a second-period contract, which is experience-rated. This is described in more detail later on.

We investigate property damages insurance coverage only, which means that the claim frequency is lower than if we looked at all claim types. We test for statistical evidence of

- policyholders with a higher claim frequency choosing high coverage, without checking whether it is due to adverse selection or moral hazard,
- moral hazard, and
- policyholder learning.

Most of the usual assumptions used in models on adverse selection are maintained in this paper: a policyholder's information is costly to observe by the insurer, the provision of the insurance is costless and the insurer is risk-neutral while the policyholders are risk-averse, having identical twice-differentiable, increasing and strictly concave utility functions. However, we relax the usual assumption that neither the frequency nor the claim size are functions of the actions of the policyholder, since a correlation between coverage and accidents is consistent not only with the existence of adverse selection but also with the existence of moral hazard.[4]

As discussed in Chiappori and Salanié (2000), it is generally a delicate task to model the claim frequency, since omission of some variables can generate spurious correlations. We use the same covariates and models as the insurer uses for the pricing scheme of this particular automobile insurance coverage. Hence, we ought not to experience the same problems of spurious effects and therefore our results should be considered rather reliable.

2.1. Testing if risky policyholders choose more coverage

The literature on adverse selection in a competitive setting builds on the influential paper Rothschild and Stiglitz (1976). One of the predictions of their model, highlighted by Chiappori and Salanié (2000), is that contracts with higher insurance coverage are chosen by policyholders who have, for example, a higher expected probability of accident (or claim frequency). Moreover, these choices should be fairly robust under adverse selection. Chiappori and Salanié suggest that the veracity of the prediction can be checked using a fairly simple test: if it is true then a positive correlation between claim frequency and coverage should be seen on observationally identical policyholders, conditional on the variables used for pricing.

We begin by testing the conditional independence of the occurrence of accidents (in this case, reported claims) and the choice of coverage. The hypothesis of zero correlation is tested in a bivariate probit model, motivated by the recommendation of Chiappori and Salanié (2000).[5]

We consider two distinct definitions of high coverage in the tests. In one definition, the amount of coverage chosen by the policyholder is deemed "high" if the deductible is below a fixed monetary threshold. In the other, the amount of coverage chosen by the policyholder is deemed "high" if the ratio of the deductible to the premium is below a fixed threshold. We wish to see if the results are different under the two different definitions. If so, it may account at least partially for the discrepancies in the results in the literature.

However, the simplicity of testing the prediction of Chiappori and Salanié has a cost. By itself, the coverage–risk correlation does not allow the identification of the type of informational asymmetry involved, if any exists. One can argue that the origin of a claim does not really matter for the pricing process, as long as the insurer cannot observe the underlying characteristics. The insurer is liable for a claim regardless of whether it is due to an endogenous risk or lack of care. However, if the insurer is interested in dealing with and reducing the informational asymmetry then it is important to know the difference. Moreover, theoretically this will affect our assumptions and conclusions: a Rothschild-Stiglitz equilibrium exists if and only if there are enough high-risk agents in the economy, under the assumption of adverse selection only. When both adverse selection and moral hazard are present, this condition is no longer true. An equilibrium may, or may fail to, exist whatever the proportion of agents of different types, depending on the parameters or the model; see Chassagnon and Chiappori (1997).

2.2. Testing for moral hazard

Although we are primarily interested in this paper about the consequence of using a particular definition of high coverage, we also test for moral hazard. Many tests to distinguish whether asymmetric information depends on moral hazard or adverse selection have been proposed in the literature.[6] Unfortunately, these tests are not applicable for the data set available to us as they are specific to the data or market structure under investigation. A more sophisticated dynamic model is employed by Abbring *et al.* (2008). They assume that policyholders seek to maximise the expectation of a discounted power utility function. Related works are those of Dionne *et al.* (2011) and Dionne *et al.* (2013).

We assume that for the experience-rated insurance contracts, and allowing for moral hazard, a policyholder has an incentive to be more cautious after experiencing a claim in one year. The incentive is that, if no claims are reported, the premium for the next policy year decreases. Consequently, if moral hazard is present, the existence of moral hazard would suggest that there is a negative correlation between claims in one year and the following year, conditional on some explanatory variables.

Thus we assume that the Danish policyholders make insurance decisions by considering only the near future, rather than their entire future lifetime.[7] Our assumption is consistent with how the insurance company prices its policies.

To see if there is evidence of moral hazard, we test the hypothesis of zero correlation between whether a claim was made or not in the year 2007, and whether a claim was made or not in the year 2008. We do the test not only on experience-rated policyholders, but also on those who buy a fixed-price product.

It may seem surprising to test the fixed-price policyholders, as the hypothesis on moral hazard does not hold for these types of insurance products. However, if the correlation between claims in consecutive years is positive, this phenomenon is called *claims migration* and it is interesting for fixed-priced products.[8]

2.3. Testing for policyholder learning

One can argue that a completely new policyholder and the insurer are equally uninformed regarding the policyholder's risk, as the former lacks experience of driving and of the insurance market, and the latter lacks experience of the former. This is called *symmetric incomplete information*; see De Garidel-Thoron (2000). In such case, it would be inefficient to draw conclusions based on the ex ante selection of contracts from the offered menu of contracts.

However, as time goes by, both the insurer and the policyholder gain more experience, which is referred to as *learning*. The learning may not necessarily occur equally for the two parties, which can lead to ex post adverse selection. Furthermore, if the policyholder then changes insurer we can assume that the information asymmetry truly exists.[9] If moral hazard is not present and a claim is followed by the policyholder decreasing their coverage, ceteris paribus, this indicates that the policyholder has become more aware of their own risk by learning.

To see if there is evidence of policyholder learning, we test the hypothesis of zero correlation between whether a claim was made or not in the year 2007, and whether the policyholder decreased their coverage or not from year 2007 to year 2008. Again, this is done conditional on the variables observed by the insurer, and using a bivariate probit model. We repeat the test but looking at whether the policyholder increased their coverage or not from year 2007 to year 2008. Unfortunately, the tests are somewhat weak since a driver may also learn from unreported "near misses", when an accident almost happens but fortunately does not occur.

3. Data, products and the GLM model

3.1. Data

The data set used is from one of the three largest Danish insurance companies and covers all data available for the insurer on personal lines automobile insurance, i.e. cars for personal usage at a maximum weight of 3.5 tonnes, from 2002 to 2008. The data set is specific for this insurer, but the information included is typical for most insurers. Thus we consider the results obtained as general, at least for the Danish automobile insurance market.

For each policyholder, the insurer has documented around 80 covariates. For instance, they are the policyholder's demographic characteristics such as age and gender for both the policyholder and the principal driver, and their residential area; the characteristics of the insured car: brand, size of engine, fuel type, model year; the period covered: the length (duration) of the period covered by the purchased policy.

3.2. Products

The insurer offers two car products for personal lines automobile insurance: one fixed-price premium product and one experience-rated premium product, with a finite number of levels. In Denmark it is mandatory for all car owners to have a third-party liability insurance. The property damages coverage that we investigate is voluntary. It covers damages on the vehicle that originate from bodily injury, collateral damages, theft, robbery, vandalism, fire, explosion, lightning and thrown objects.

The eligibility criteria for the fixed-price product are the following: the user has to be at least 25 years of age, and has not reported any claims on the third-party liability coverage during the last five years and has not reported any claims during the last three years on the property damages coverage, though three glass damage claims are accepted. These criteria are specific to this insurer, but similar products are offered by most Danish insurers.

Almost anyone can purchase the experience-rated product. The level that a policyholder starts on depends on age and number of years without claims. To get the lowest premium in this product, the policyholder must fulfil the following criteria: at least eight years of claim-free driving, of which the last three must be totally claim-free, though glass damage claims are accepted. Note that there is no legal regulation of the rating scheme on the Danish insurance market, as in the French or Canadian ones.[10]

The policyholders are furthermore sub-divided into “new” and “repeat” policyholders, since we think it is more likely to find adverse selection in the group of new policyholders than in the group of existing policyholders. The “new“ group are the new policyholders who have an automobile insurance policy with a seniority of less than one year. The repeated policyholders have held an automobile insurance policy for at least one year with the present insurer (though not necessarily on the same car).

Both types of policyholders choose their level of deductible. A higher level of deductible means that the policyholder has a lower insurance coverage, and vice versa. There are many levels of deductibles in Denmark compared to other markets. In 1990, the levels of deductible given in Danish kroner (DKK) were set at 500, 1,000, 1,500, ..., 10,000. Each year the deductibles have been adjusted. For example, in 2008 the levels were 919, ..., 18,970 in DKK, with an average level of 4,176 DKK. In comparison, the average premium in 2008 of a motor insurance policy is 4,901 DKK. Figure 1 shows the distribution of the deductibles chosen by the policyholders in 2008, discounted to their value in the year 1990.

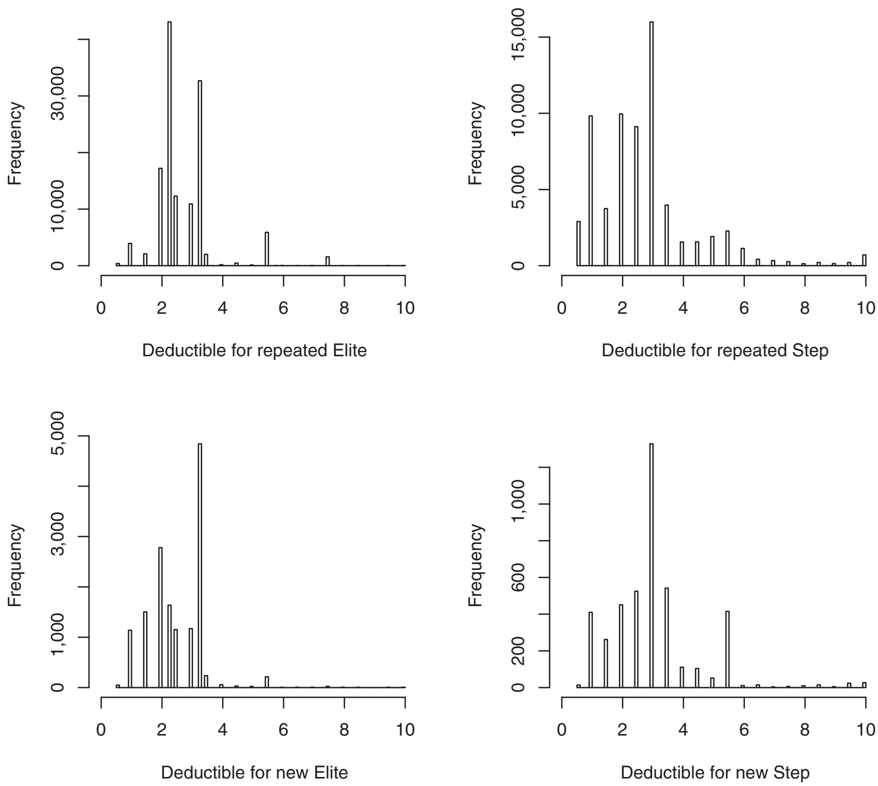

FIGURE 1: Distribution of deductibles chosen by policyholders in 2008, discounted to their 1990 value and expressed in thousands of monetary units. *Elite* denotes the fixed-price policyholders and *Step* denotes the experience-rated policyholders.

Policyholders with registered payment default are dealt with by special rules, and they are omitted in this study.

3.3. GLM estimation and data issues

First we perform the same procedure as in the pricing department of the insurer to find the covariates to be used when pricing the insurance coverage. The covariates for policyholder $i = 1, 2, \ldots$ and calendar year $j = 2002, \ldots, 2008$ are represented by the column vector $\mathbf{x}_{ij}$. The corresponding exposure weight (i.e. the duration) ω_{ij} is measured in policy years. As is standard in insurance applications of generalised linear models (GLMs), separate analyses are performed for the claim frequency and the average claim cost. We are interested in the claim frequency only, since we want to compare our results with the previous literature.

We assume that the expected claim frequency follows a (ω_{ij}-weighted) Poisson GLM, which means that the expected number of claims ν_{ij} can be written

TABLE 1

SELECTION OF THE PARAMETER ESTIMATES FOR A GLM MODEL FOR THE EXPECTED CLAIM FREQUENCY.

		Analysis of Parameter Estimation			
Parameter		Estimate	Std Error	χ^2	Prob. > χ^2
Class variable 1	Yes	−1.8306	0.2419	57.25	$<10^{-4}$
Class variable 1	No	−2.2395	0.2390	87.82	$<10^{-4}$
Class variable 2	0	−0.2128	0.0363	34.28	$<10^{-4}$
Class variable 2	1	0.0000	0.0000	–	$<10^{-4}$
Variable 1 (Deductible)		−0.0751	0.0061	151.65	$<10^{-4}$
Variable 2		−0.0589	0.0080	54.42	$<10^{-4}$
Variable 3		0.0521	0.0082	40.34	$<10^{-4}$
Variable 4		0.0441	0.0039	125.05	$<10^{-4}$
Variable 5		−0.0029	0.0008	13.40	0.0003
Variable 6		−0.0336	0.0026	167.00	$<10^{-4}$
Variable 7		−0.0215	0.0068	10.00	0.0016
Variable 8		0.8624	0.0523	271.73	$<10^{-4}$
Variable 9		−0.9178	0.0969	89.69	$<10^{-4}$
Variable 10		0.0350	0.0028	159.41	$<10^{-4}$
Variable 11		−0.0297	0.0031	94.45	$<10^{-4}$

Note: There are two class variables and 11 continuous variables. Variable 1 is the level of deductible given in thousands of DKK and discounted to 1990, denoted by d_{ij}. The other variables can be, for example, age of the driver, age of the insured car and seniority of the policyholder. The actual variables used remain unspecified due to confidentiality reasons. The estimates are based on information about 182,031 policyholders who held an active insurance policy from 2002 to 2006.

as

$$\nu_{ij} = \omega_{ij} \exp(\boldsymbol{\beta}^\top \mathbf{x}_{ij}),$$

in which $\boldsymbol{\beta}$ is a column vector of parameters to be estimated, and $\boldsymbol{\beta}^\top$ denotes the transpose of $\boldsymbol{\beta}$. We use the information about 182,031 policyholders who held an active insurance policy during the years 2002–2006 to estimate $\boldsymbol{\beta}$.

The results of the GLM estimation for some of the components of $\boldsymbol{\beta}$ are shown in Table 1. Due to confidentiality reasons, the actual variables used in the GLM regression are unspecified. Although we find the gender of the principal driver significant,[11] it is not used in the pricing scheme of the property damages coverage due to interpretation difficulties. It was therefore excluded in the forthcoming analysis.

The level of deductible chosen by policyholder i in year j, and discounted back to their value in the year 1990, is denoted d_{ij}. The deductible variable d_{ij} has a corresponding GLM parameter estimate of −0.0751. This means that policyholders with higher deductibles (i.e. lower coverage) report fewer claims. Naturally, policyholders with lower deductibles are able to file claims for accidents with damage costs that are too small to claim under policies with a higher deductible. In insurance data we can only observe claims, not accidents. The decision to report a claim is usually made by the policyholder, and should be considered as either a response to or an outcome of a choice based on incentives. If the expected costs of reporting a claim exceed the expected compensation then the policyholder can choose not to file the accident. For instance, the experience-rated policyholder may expect to have a higher future premium as a result of reporting a claim, or it may be that the expected costs of the claim are less than the deductible. Hence, if we count all claims reported by low-deductible policyholders then we expect more claims to be submitted by the low-deductible policyholders, even if the two groups are identical in their risk type.

One way to deal with the bias, suggested in Chiappori and Salanié (2000), is to omit all accidents in which only one vehicle was involved. An even more restrictive way is to consider only accidents involving bodily injuries, since it is mandatory to report these kind of accidents. However, this requires a lot more detailed level of documentation and processing of data and reduces the number of accidents radically.

Instead, we only count claims with a severity that exceed the highest level of deductible, following Cohen (2005). Such claims should be submitted by all policyholders, regardless of their chosen level of deductible, which means that we treat all policyholders fairly. After this truncation, the GLM parameter estimate of d_{ij} is 0.0357 so that policyholders with higher deductibles (i.e. lower coverage) report more claims. However, the estimate is no longer significant at a reasonable level, as the corresponding p-value is 0.1249. Thus we have reduced, if not removed, the spurious correlation between the level of deductible and the number of claims. Note that this comes at the cost of a lower claims frequency.

Additionally, we separate claims into those in which the insured is at fault and those in which the insured is not at fault. The reason for this is that, if another driver is to blame for the accident, the information on the insured's risk type may not be conveyed. Furthermore, in addition to removing all claims with a severity above the highest level of deductible from the data, we do not use the further information associated to drivers who had several claims during one year. They are relatively few in number; only 0.082% of all policyholders had more than one claim in 2008.

4. Data analysis

4.1. A bivariate probit model

For each analysis, we use a bivariate probit model. For policyholder i with characteristics drawn from the random vector $\mathbf{X}_{ij}$ in year j, the bivariate probit model for two zero-one indicator random variables Y_{ij} and Z_{ij} is

$$Y_{ij} = \mathbb{1}\left\{\boldsymbol{\beta}^\top \mathbf{X}_{ij} + \epsilon_{ij} > 0\right\}, \qquad Z_{ij} = \mathbb{1}\left\{\boldsymbol{\gamma}^\top \mathbf{X}_{ij} + \eta_{ij} > 0\right\},$$

and

$$\begin{pmatrix}\epsilon_{ij}\\ \eta_{ij}\end{pmatrix} \Bigg| \mathbf{X}_{ij} = \mathbf{x}_{ij} \sim \mathcal{N}\left(\begin{pmatrix}0\\0\end{pmatrix}, \begin{pmatrix}1 & \rho\\ \rho & 1\end{pmatrix}\right),$$

in which $\mathbb{1}\{\cdot\}$ is the zero-one indicator function, $\boldsymbol{\gamma}$ is a column vector of parameters and ρ is the correlation. The latter two parameters are estimated from the data.

If the correlation ρ equals zero then, by the assumption of normality, it follows that Y_{ij} and Z_{ij} are conditionally independent random variables. The bivariate probit test, used in Chiappori and Salanié (2000) and Cohen (2005), is to test the null hypothesis that the correlation ρ equals zero (see Casella and Berger 2002 for an introduction to statistical inference).

In all of the tests performed, the random variable Y_{ij} represents the risk of policyholder i in year j: it denotes whether policyholder i has made a claim or not in the year j. Define

$$y_{ij} = \begin{cases} 1 & \text{if policyholder } i \text{ had at least one claim in which they are} \\ & \text{judged to be at fault in year } j, \\ 0 & \text{otherwise} \\ & \text{(i.e. either no claim or policyholder } i \text{ not at fault in year } j). \end{cases}$$

We assume that each y_{ij} is a sample from Y_{ij}.

The random variable Z_{ij} represents the coverage, with its exact interpretation depending on the chosen test, as detailed in the sequel.

4.2. Testing for coverage–risk correlation

To ease the interpretation of the results and reduce the risk of spurious effects due to unforeseen expectations of future changes in premium, we start by focusing on the fixed-price policyholders. The model was estimated using the information on 125,437 fixed-price policyholders who held an active insurance policy in 2008. There are 143,919 observations for all fixed-price policyholders and 14,550 observations for the new fixed-price policyholders only.

4.2.1. *Fixed-price policyholders and monetary threshold.* For the first coverage–risk correlation test on the fixed-price policyholders, we define

$$z_{ij}(T) = \begin{cases} 1 \text{ if } d_{ij} \leq T, \text{ i.e. policyholder } i \text{ has chosen high coverage in year } j, \\ 0 \text{ if } d_{ij} > T, \text{ i.e. policyholder } i \text{ has chosen low coverage in year } j, \end{cases}$$

in which T is a threshold deductible. We assume that each $z_{ij}(T)$ is a sample from the coverage random variable $Z_{ij}(T)$.

The GLM parameter estimate for the variable $z_{ij}(T)$ for different choices of the threshold deductible T are displayed in Table 2 for the fixed-price policyholders. This gives a preliminary indication of the existence of a relationship between coverage and risk. We see that it is possible to find a positive and statistically significant parameter, indicating that the claims are more common for fixed-price policyholders who choose a high coverage (i.e. a low deductible). However, the choice of threshold deductible matters. For example, the estimate

TABLE 2

GLM ESTIMATE OF THE PARAMETER FOR $z_{ij}(T)$ FOR FIXED-PRICE POLICYHOLDERS.

		Monetary Threshold Deductible T				
	500	1,500	2,500	3,500	4,500	5,500
Estimate for $z_{ij}(T)$	0.235***	0.182***	0.0401*	0.0215	0.0003	0.1663**
Fixed-price policyholders with high coverage	0.2%	5.4%	61.3%	94.5%	94.9%	98.9%

Note: ***, ** and * indicate significance at 1%, 5% and 10% level, respectively. The variable $z_{ij}(T)$ replaces the level of deductible d_{ij} in the GLM model. All the remaining GLM estimates are the same as in Table 1. The estimates are based on the same data and time period as in Table 1. The percentage of policyholders who choose a high coverage (i.e. a deductible less than T) for each group is shown below the estimate for z_{ij}.

TABLE 3

ESTIMATED COVERAGE-RISK CORRELATION AND TAKE-UP FOR FIXED-PRICE POLICYHOLDERS.

		Monetary Threshold Deductible T				
	500	1,500	2,500	3,500	4,500	5,500
All fixed-price policyholders ρ	0.0027	0.0003	−0.0001	−0.0049	−0.0056	0.0034
All fixed-price policyholders with high coverage	0.2%	5.4%	61.3%	94.5%	94.9%	98.9%
New fixed-price policyholders ρ	0.0230	0.0036	0.0187	−0.0206	−0.0312**	−0.0515***
New fixed-price policyholders with high coverage	0.3%	18.9%	62.5%	97.3%	98.0%	99.6%

Note: *** and ** indicate significance at 1% and 5% level, respectively. Estimated correlation between the risk variable $Y_{i,2008}$ and the coverage variable $Z_{i,2008}(T)$ for fixed-price policyholders. The percentage of policyholders who choose a high coverage (i.e. a deductible less than T) for each group is shown below the correlation estimate.

is not statistically significant at $T = 3{,}500$, but it is at the lower threshold $T = 1{,}500$ and also at the higher threshold $T = 5{,}500$.

We apply the bivariate probit test with the risk random variable $Y_{i,2008}$ and the coverage random variable $Z_{i,2008}(T)$ for each policyholder i. For all the coverage–risk tests, the entry for the deductible is removed from the covariate vector $\mathbf{x}_{ij}$, and the parameters $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ are adjusted likewise. The resultant adjusted covariate vector $\bar{\mathbf{x}}_{ij}(T)$ and adjusted parameter vectors $\bar{\boldsymbol{\beta}}$ and $\bar{\boldsymbol{\gamma}}$ replace their counterparts in the probit model.

Table 3 displays the estimated coverage–risk correlation for different values of the threshold deductible T for all of the fixed-price policyholders and for the new fixed-price policyholders only.

The correlation estimate for all fixed-price policyholders is sometimes negative, contradicting the prediction of the standard theory of asymmetric information. However, none of the estimates are statistically significant at a reasonable level and may well be the result of spurious effects.

For the new fixed-price policyholders, we find a negative correlation for some choices of the threshold deductible. This means that policyholders with a high coverage (i.e. a deductible below the chosen threshold) also have fewer claims. However, the negative correlation is only statistically significant when the majority of new fixed-price policyholders have a high coverage. For example, for the 99.6% of the new fixed-price policyholders who choose a deductible below 5,500 DKK, the estimated correlation of −0.0515 is significant at the 1% level. This means that the remaining 0.4% of the new fixed-price policyholders, who choose a low coverage, are likely to have more claims. This is not we expect to see, given the theory of adverse selection and moral hazard. It could be explained by advantageous selection models, which assume that lower-risk policyholders are both more cautious and risk averse, and thus choose a lower deductible; see de Meza and Webb (2001).

In fact, the statistically significant negative correlation is because some young drivers are forced to have a high level of deductible in order to be allowed to buy an insurance policy. They are expected to have more claims, which does seem to be the case. Thus the negative correlation is not a consequence of the young drivers' own choices, but rather due to policy restrictions.

In conclusion, when expressing coverage as a monetary amount, we do not find evidence of asymmetric information in either the set of all fixed-price policyholders or the subset of new fixed-price policyholders only. There is not enough evidence to reject the null hypothesis that risk and coverage are conditionally independent, regardless of the level of deductible at which the policyholders' coverage is labelled as high.

We continue testing the coverage–risk correlation by investigating what happens if coverage is expressed relative to the deductible, as is done in Cohen (2005).

4.2.2. *Fixed-price policyholders and relative threshold.* For the second coverage-risk correlation test on the policyholders, we define

$$z_{ij}^{\text{rel}}(R) = \begin{cases} 1 \text{ if } d_{ij}/P_{ij} \leq R, \text{ i.e. relatively high coverage,} \\ 0 \text{ if } d_{ij}/P_{ij} > R, \text{ i.e. relatively low coverage,} \end{cases}$$

in which P_{ij} is the premium charged to policyholder i in year j, and R is a relative threshold deductible. We assume that each $z_{ij}^{\text{rel}}(R)$ is a sample from a random variable $Z_{ij}^{\text{rel}}(R)$, the relative coverage random variable.

Again, we apply the bivariate probit test outlined in Section 4.1, with the risk random variable $Y_{i,2008}$ and the relative coverage random variable $Z_{i,2008}^{\text{rel}}(R)$ for each policyholder i. Table 4 provides the estimates of the relative coverage–risk correlation for all and new fixed-price policyholders, respectively.

For the higher relative thresholds, we find a positive correlation at a statistically significant level of 1%. For example, for a relative threshold $R = 4$, all fixed-price policyholders have an estimated correlation of 0.0108 and the new fixed-price policyholders have an estimated correlation of 0.0352, both at the 1%

TABLE 4

ESTIMATED RELATIVE COVERAGE-RISK CORRELATION AND TAKE-UP FOR FIXED-PRICE POLICYHOLDERS.

	Relative Threshold Deductible R				
	1	2	3	4	5
All fixed-price policyholders ρ	−0.0026	0.0044	0.0064*	0.0108***	0.0115***
All fixed-price policyholders with high coverage	19.0%	83.7%	95.4%	97.2%	97.7%
New fixed-price policyholders ρ	−0.0113	0.0109	0.0199	0.0352***	0.0229*
New fixed-price policyholders with high coverage	36.1%	76.1%	82.4%	83.2%	83.4%

Note: *** and * indicate significance at 1% and 10% level, respectively. Estimated correlation between the risk variable $Y_{i,2008}$ and the relative coverage variable $Z^{\text{rel}}_{i,2008}(R)$ for fixed-price policyholders. The percentage of policyholders who choose a high relative coverage for each group is shown below the correlation estimate.

TABLE 5

ESTIMATED COVERAGE-RISK AND RELATIVE COVERAGE-RISK CORRELATION FOR EXPERIENCE-RATED POLICYHOLDERS.

	Threshold Type	
	Monetary Units $T = 4{,}000$	Relative to Premium $R = 4.5$
New experience-rated policyholders ρ	0.0120	−0.0240
Repeat experience-rated policyholders ρ	0.0029	0.0067

Note: None of the correlation estimates are significant. Estimated correlation between the risk variable $Y_{i,2008}$ and either the coverage variable $Z_{i,2008}(T)$ or the relative coverage variable $Z^{\text{rel}}_{i,2008}(R)$, for experience-rated policyholders.

level. Thus there is evidence to reject the hypothesis that risk and (relative) coverage are conditionally independent. The omission of the gender variable does not explain the asymmetry, since we found the correlation to be still statistically significant when the gender variable is added to the model.

In conclusion, when using the notion of relative coverage, we find evidence of asymmetric information for both all and new fixed-price policyholders.

4.2.3. *Experience-rated policyholders.* Finally, we run both types of coverage–risk correlation tests on the experience-rated policyholders. The estimation is based on data from the year 2008. There are 3,861 observations for the new experience-rated drivers and 53,200 observations for the repeat experience-rated policyholders. A selection of the results is shown in Table 5.

For the policyholders with an experience-rated insurance product, we are unable to find any correlation that is statistically significant at a reasonable level. Thus there is not enough evidence to reject the null hypothesis that risk and coverage are conditionally independent for the experience-rated policyholders.

4.2.4. *Discussion of coverage-risk correlation results.* When we express the deductible relative to the paid premium, we can find a positive coverage–risk correlation for both new and repeat fixed-price policyholders at the 1% significance level (see Table 4). According to Rothschild and Stiglitz (1976), for adverse selection to exist neither insurers nor their customers have to be perfectly informed about the differences in risk properties that exist among individuals. Our results suggest that the fixed-price policyholders who choose a low coverage (i.e. high deductible) are aware of their risk.

When a coverage–risk correlation is found for the fixed-price policyholders, the population is split so that most policyholders have a high coverage (i.e. a low deductible): at a relative threshold deductible of 4, about 83% of the new fixed-price policyholders and 97% of all fixed-price policyholders have high coverage. Our finding is consistent with Rothschild and Stiglitz (1976), which says that, under adverse selection, an equilibrium exists only if there are enough high risks. The test identifies the few "good" (i.e. low risk, low relative coverage) policyholders, who could then be offered additional products by the insurer as in Donnelly *et al.* (2013). However, the insurer would not have found any such policyholders if they had attempted to identify them using the threshold deductible expressed in monetary terms.

A positive coverage–risk correlation for a fixed-priced product is also found by Cohen (2005) when looking at drivers with three or more years of driving experience. Even though we lack direct information on the number of years with driving licence, it is implicit that fixed-price policyholders have held a licence for three years or more: to be able to purchase the product, they must be claims-free for at least three years. Moreover, the analysis in Cohen is analogous to our risk-relative coverage test, in that the deductibles are expressed in terms of premiums paid. However, there are differences between the menu of deductibles offered to the Danish drivers of our study and the Israeli drivers of Cohen's study.

Figure 2 shows the distribution of the deductible in relation to the paid premium for each policyholder group in our Danish data. The appearances of the histograms are rather smooth except for the spikes in the tail where the deductible is approximately four times the paid premium. The deductibles are generally of the same size as the premium. This is quite different from the Israeli market described in Cohen (2005), in which there are only four levels of deductible offered to policyholders and each deductible has a premium associated with it. The low deductible is set at approximately 30% of the regular premium, the regular deductible at 50%, a high deductible is considered to be 90% and a very high deductible is around 130% of the regular premium. In the context of our Danish data set, almost all the chosen deductibles of the policyholders are to be considered high or very high, according to Cohen's gradation. Indeed, the threshold deductible of 4 at which we find a positive risk-relative coverage correlation at a statistically significant level corresponds roughly to an Israeli policyholder choosing a "very high" deductible. In Cohen's data, less than 2% of policyholders choose a high or very high deductible, and she excluded them from her analysis. The framing of the deductible menu to policyholders may also

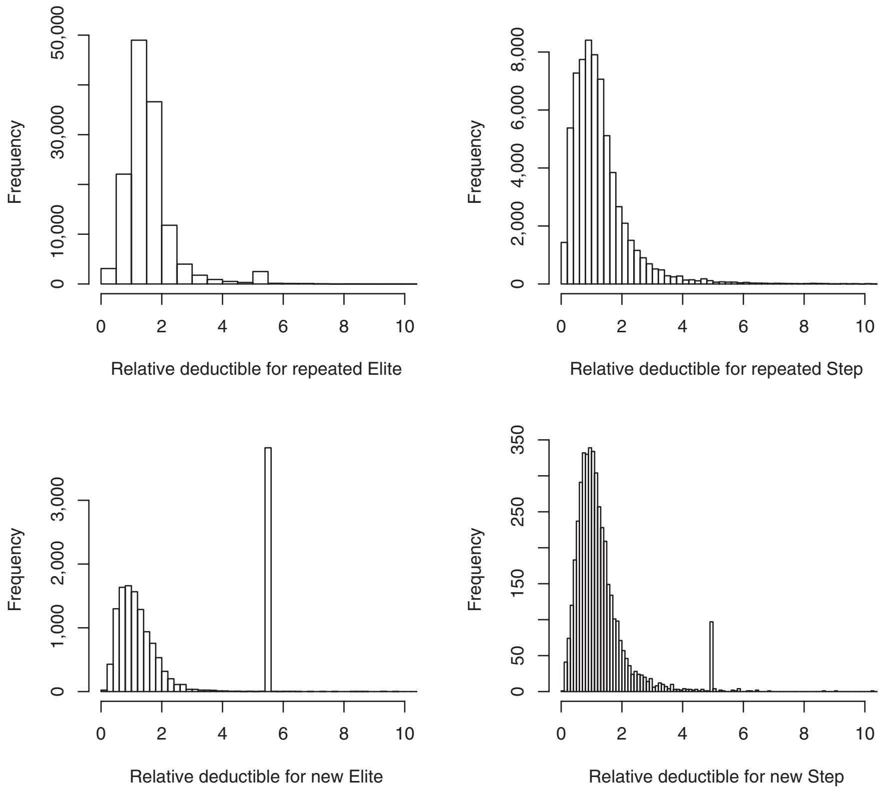

FIGURE 2: Distribution of the ratio of the deductibles to the paid premium in 2008. *Elite* denotes the fixed-price policyholders and *Step* denotes the experience-rated policyholders.

affect their choice: the deductibles are described to the Israeli policyholders as low, regular, high or very high, expressed relative to the premium paid, whereas the Danish policyholders are offered a menu of 20 deductibles expressed in monetary terms, without reference to the premium paid. However, it is difficult to see how our results could be adjusted to allow a direct comparison with those of Cohen (2005).

We do not find any evidence of a coverage–risk correlation for the experience-rated policyholders. Chiappori and Salanié (2000) finds the same result for an experience-rated French automobile product. Our results suggest that the pricing structure of the experience-rated product is sufficiently good to remove the effects of any possible asymmetric information. Alternatively, it might be explained that, at 3,861, the number of observations for the new experience-rated policyholders are too few. However, the same explanation looks weak when applied to the repeat experience-rated policyholders, as there are 53,200 observations for them. A third explanation is that we have not taken into consideration expectations of increases of future premiums when truncating the claims. Prendergast (1992) concludes that bonus-malus systems

TABLE 6

ESTIMATED CORRELATION BETWEEN THE RISK VARIABLES IN 2007 AND 2008.

	Policyholder Type			
	All Fixed-Price	New Fixed-Price	All Experience-Rated	New Experience-Rated
ρ	0.0504***	0.0356***	0.0448***	0.0610***
Number of policyholders	57,063	8,774	24,139	2,421

Note: *** indicates significance at 1% level. Estimated correlation between the risk variables in consecutive years, $Y_{i,2007}$ and $Y_{i,2008}$, for fixed-price and experience-rated policyholders.

(as when experience-rating is used) and a lack of information pooling between insurers (as in the Danish insurance market) constitute an implicit deductible. They can provide incentives for both self-protection and self-insurance; see Ehrlich and Becker (1972).

4.3. Moral hazard tests

A positive coverage–risk correlation is a central prediction not only of adverse-selection models but also of moral hazard models. Therefore, we do a test to see if there is evidence of moral hazard in our data.

The theory of moral hazard predicts that a claim is followed by fewer claims; see Abbring *et al.* (2003b). Consequently, we should see a negative correlation between the claims in consecutive years. We estimate the correlation between the risk random variables $Y_{i,2007}$ and $Y_{i,2008}$ in the conditional bivariate probit model given in Section 4.1. The estimation is done on policyholders who held an active insurance policy in both 2007 and 2008, and who have no missing values in the covariates.

The results in Table 6 show that we do not find evidence of moral hazard for any group of policyholders. Instead we find a positive claims occurrence correlation between 2007 and 2008, which lends support to applying experience-rated pricing. It indicates that policyholders are unable to change their risk behaviour sufficiently, at least not from one year to the next; poor drivers remain so, at least for a while.

However, this may also be a spurious dependency that we observe, due to unobserved heterogeneity due to using too few covariates. Abbring *et al.* (2003a) propose how to distinguish moral hazard from dynamic selection on unobservable factors. However, as the focus of our paper is on the robustness of the tests for asymmetric information, we do not investigate this further.

4.4. Policyholder learning tests

To investigate learning, we estimate the correlation between the claims made in the year 2007 and the decrease in coverage between 2007 and 2008. Recall that

TABLE 7

ESTIMATED CORRELATION BETWEEN THE 2007 RISK VARIABLE AND CHANGE IN COVERAGE FROM 2007 TO 2008.

	Policyholder Type			
	All Fixed-Price	New Fixed-Price	All Experience-Rated	New Experience-Rated
Decrease in coverage ρ	−0.00431	−0.0157	0.0249***	0.03617
Increase in coverage ρ	0.00277	0.0149	−0.00567	0.0163

Note: *** indicates significance at 1% level. Estimated correlation between the risk variable $Y_{i,2007}$ in 2007 and the change in the level of deductible from 2007 to 2008, for fixed-price and experience-rated policyholders. The estimation is done using the bivariate probit for $Y_{i,2007}$ and either the zero-one indicator variable $\mathbb{1}\{d_{i,2008} - d_{i,2007} > 0\}$ for the decrease in coverage from 2007 to 2008 test, or the zero-one indicator variable $\mathbb{1}\{d_{i,2008} - d_{i,2007} < 0\}$ for the increase in coverage test.

d_{ij} is the level of deductible chosen by policyholder i in year j, and expressed in 1990 values. Thus if policyholder i decreases their coverage between 2007 and 2008, by choosing a higher level of deductible in 2008, then $\mathbb{1}\{d_{i,2008} - d_{i,2007} > 0\} = 1$, and otherwise $\mathbb{1}\{d_{i,2008} - d_{i,2007} > 0\} = 0$. The correlation between $Y_{i,2007}$ and $\mathbb{1}\{d_{i,2008} - d_{i,2007} > 0\}$ was estimated in the bivariate probit model of Section 4.1.

We also estimated the correlation between the claims made in the year 2007 and the increase in coverage between 2007 and 2008. For the latter, we used the zero-one indicator function $\mathbb{1}\{d_{i,2008} - d_{i,2007} < 0\}$, which takes value one if policyholder i increased their coverage from 2007 to 2008 (by choosing a lower level of deductible in 2008), and value zero otherwise. All the results are shown in Table 7.

When we investigate the decrease in coverage between 2007 and 2008, we find a significant correlation only for the experience-rated drivers. However, an experience-rated driver may decrease their coverage after a claim as a way of reducing the renewal premium to compensate for the post-claim increase in premium. It also indicates that the policyholder is confident that the claim was coincidental and that they do not expect any claims in the following insurance period.

One possible explanation for the lack of significant correlation is that repeat policyholders and the new fixed-price drivers are already aware of their level of risk, and have purchased the insurance at a certain level of deductible based on their risk assessment. The fixed-price drivers take action on the occurrence of claims and change their deductible, while the experience-rated drivers do not have to. The new fixed-price drivers might be more inexperienced and are less able to make a conclusion based on their claims experience, or perhaps they agree with the increased premium.

5. Conclusions

We find evidence of asymmetric information in the Danish data. We do not find evidence of moral hazard. The way the thresholds, for which the coverage–risk correlation is statistically significant, separate the policyholders is consistent with the Rothschild-Stiglitz model, which assumes adverse selection without moral hazard. Based on the tests performed, we attribute the cause of the positive coverage–risk correlation in our investigation to adverse selection.

Our main conclusion is that our results suggest that the tests for asymmetric information are not robust. Evidence for the existence of asymmetric information depends on how coverage was defined, either in monetary terms or relative to the premium paid, and at what level it was considered to be high. Further investigation is required to understand the underlying reasons for this. For example, it may be due to the particular form of the policyholders' utility function.

On a practical note, it is important for the insurer to monitor the deductible levels, as the deductible is often seen as a simple and efficient way to avoid small claims that are relatively expensive to process. However, if the level of deductible causes adverse selection, this has to be taken into consideration. On the other hand, the insurer's profit might be higher for insurance with high coverage, contrary to the prediction of competitive markets. This might compensate for the effects of adverse selection.

We find evidence of policyholder learning, but only for repeat policyholders with an experienced-rated product, for whom adverse selection is not present. Consequently, one explanation might be the policyholder maintaining or reducing their total premium after they have experienced a claim. This means that the experience-rated policyholders are sufficiently aware of their intrinsic risk and choose the amount of coverage, i.e. level of deductible, based on this. However, they are not able to change their risk behaviour sufficiently enough to influence the outcome in a significant way. The experience-rated policyholders are either unaware of their own risk or they are risk averse. Alternatively, the pricing scheme of the experience-rated product is sufficiently good to remove the effects of any possible asymmetric information.

We find a positive claim occurrence dependency, called claims migration, which indicates that poor drivers remain bad for some time. In other words, policyholders are generally unable to change their risk behaviour, nor do they learn from their claims, at least not from one year to the next.

Notes

1. Cutler (2002) finds evidence of this correlation in a health insurance market. Finkelstein and Poterba (2004) find this correlation in an annuity market. A recent survey of empirical studies that test for asymmetric information is Chiappori and Salanié (2013).

2. Even though Chiappori *et al.* (2006) conclude that a positive coverage–risk correlation would be a natural and robust consequence of the assumption of a competitive market.

3. The definition of Chiappori and Salanié (2000) includes policies with the deductible expressed as a fixed monetary amount and those with it expressed relative to the premium. However, they remark that for their data it would make the model too complicated to allow for the different

levels of deductible and, in any case, the differences between deductibles are small compared to the differences between complete and partial coverages. For Cohen (2005); Dionne *et al.* (2001); Saito (2006), which relative definition of high coverage is chosen appears to be determined by the menu of choices offered to the policyholders.

4. For recent work investigating whether drivers' precautions are influenced by the accident costs they expect to bear, see Abbring *et al.* (2003b) and Cohen and Einav (2003).

5. Puelz and Snow (1994) consider an ordered logit formulation for the choice of deductible in which the observed number of accidents is introduced among the explanatory variables. They estimate two structural equations: the demand function for a deductible and a premium function that relates different pricing variables to the observed premium. They find a significant correlation between coverage and occurrence of accidents. However, due to possible non-linear dependencies in the pricing variables, their linear modelling procedure is not sufficient to test the accident–coverage correlation that we are interested in; see Dionne *et al.* (2001) and Chiappori and Salanié (2000).

6. Abbring *et al.* (2003b) and Chiappori and Salanié (2000) are specific to the French insurance system, since they make use of the bonus-malus coefficient of the French experience-rating scheme and the rules for how this can be transferred to the children of policyholders with maximum price reduction. See also Cohen and Einav (2003) for other possible tests.

7. The general question of which economic theory explains actual insurance decision-making has not been definitively answered. There does not appear to be compelling experimental evidence to support one particular theory over another. Kunreuther and Pauly (2005) discuss many of the features seen in insurance markets that contradict standard economic models of choice and decision-making. Related papers include Austin and Fischhoff (2010), who study the decision of whether to purchase collision coverage and, if so, what deductible level to choose, through in-depth interviews of insured drivers in Pennsylvania. They do not find support for the expected utility theory prediction that more risk-averse consumers buy more insurance. Similarly, Gneezy *et al.* (2006) suggest that there are choice situations in which decision-makers discount lotteries for uncertainty in a manner that cannot be accommodated by standard models of risky choice, such as expected utility theory.

8. For a survey in experience rating and credibility theory, see Bühlmann and Gisler (2005). Frangos and Vrontos (2001) detail an interesting optimal bonus-malus system with a frequency and severity component, with an extension by Angers *et al.* (2006). More recent developments using claim migration are found in Englund *et al.* (2008) and Englund *et al.* (2009).

9. Cohen (2005) finds evidence of such asymmetric information for new policyholders with three or more years of driving experience, which has been unobservable for the insurer. We are not able to investigate this since the number of years with a driving license is not included in our data set.

10. The regulations of the French automobile insurance market are described in Chiappori and Salanié (2000) and Richaudeau (1999), and the Canadian ones in Dionne *et al.* (2001).

11. If we set a dummy variable equal to 1 for female drivers and zero for male drivers, the parameter estimate of this variable is 0.0994 with a significance level of less than 0.0001.

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