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Abstract

We examine the effects of ex post revelation of information about the risk type or the risk-reducing behavior of insureds in automobile insurance markets both for perfect competition and for monopoly. Specifically, we assume that insurers can offer a contract with information revelation ex post, i.e., after an accident has occurred, in addition to the usual second-best contracts. Under moral hazard this always leads to a Pareto-improvement of social welfare. For adverse selection we find that this is also true except when bad risks under self-selecting contracts received an information rent, i.e., under monopoly or under competition with cross-subsidization from low to high risks. Regulation can be used to establish Pareto-improvement also in these cases. Privacy concerns do not alter our positive welfare results.

Keywords: information moral hazard, adverse selection, insurance

JEL classification: D82, G22

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We examine the effects of ex post revelation of information about the risk type or the risk-reducing behavior of insureds in automobile insurance markets both for perfect competition and for monopoly. Specifically, we assume that insurers can offer a contract with information revelation ex post, i.e., after an accident has occurred, in addition to the usual second-best contracts. Under moral hazard this always leads to a Pareto-improvement of social welfare. For adverse selection we find that this is also true except when bad risks under self-selecting contracts received an information rent, i.e., under monopoly or under competition with cross-subsidization from low to high risks. Regulation can be used to establish Pareto-improvement also in these cases. Privacy concerns do not alter our positive welfare results.

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1 Introduction

This paper examines the possibility of reducing moral hazard and adverse selection in automobile insurance markets when the behavior of the insureds, which is related to the risk of accident, can ex post be observed or when the risk type can be revealed to the insurer before he pays the coverage. This research is motivated by the fast progress in automobile electronics engineering in recent years, which is, among other things, reflected in increasing performance and decreasing costs of the constituting electronic parts.[1] Above all, this trend is manifested through improved sensors which are already

[1] See e.g. Mattern (2003, 5-10).

able to detect mileage, speed and acceleration, braking,[2] the distance to other traffic participants or the exact location and route of a vehicle[3]. A recent example is the device "TripSensor" with a corresponding service related to it, introduced in August 2004 by the US automobile insurer Progressive.[4] Experts in electronics anticipate the design of ever more sophisticated tracking applications in the near future which will be able to detect, collect, and process information about the adherence to traffic signs and traffic regulation, the technical condition of the car[5], and even precisely record the maneuvers of the vehicle in the limits of several cm.[6] Furthermore personal identification and the observation of a considerable part of the behavior of the driver will be conceivable (e.g. the degree of attention[7], the usage of driving belts, phone calls, spirits consumption etc.[8]). The reason for this information to be of interest to insurers is found in the strong relationship between the observed characteristics and the behavioral patterns of the drivers with their individual risks of accident. Thus, according to statistical data, the most common reasons for accidents are excessive speed, violation of the right of way or of the minimum distance, wrong turning, spirits consumption, and wrong overtaking.[9] Empirical evidence shows also a strong positive correlation between the number of miles driven or late night driving (especially on weekends) and the risk of having an accident.[10] In principle, all of these data could individually be observed with the described electronic devices. The potential use of this possibility can be discovered when looking at the present situation.

Currently, apart from offering different self-selecting deductibles or coverage levels, insurers try to approach the actual risk of the insureds by categorizing them into risk groups according to personal and automobile-related data. These include age, sex, pro-

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2 See e.g. Spiegel Online.

3 See e.g. "GPS Warehouse".

4 See Progressive Inusrance Corp.

5 Oberholzer (2003, 434); Hitachi.

6 Herrtwich (2003, 71-72), Coroama / Höckl (2004, 2). Despite the restrictions of the state-of-the-art, the technology currently used by Progressive Insurance Corp. has the same intended purpose.

7 Currently the system performing this task consists of a computer and a camera, which tracks the frequency of blinking. As soon as the blinking slows down, an alarm signal is activated. Since falling asleep is a common reason for accidents, this application could, apart from tracking the behavior, contribute to safer driving (see "Autokiste").

8 Oberholzer (2003, 434).

9 See the statistical data of ADAC.

10 Progressive Insurance Corp.

fession, date of issue of the driving license, make of car, declared mileage. The very nature of these data implies a rather imprecise calculation of individual risk which can lead to very heterogeneous risk classes and from the viewpoint of the insured – to a very unfair categorization.[11] Another way of dealing with asymmetric information is the yearly adjustment of the insurance premiums according to past accidents which serves to set incentives for safer driving on the one hand and on the other hand it corresponds to the continuous revelation of risk type to the insurer with time. The disadvantages of premium adjustment lie in the long period of time needed in order to find out the risk type of a given driver and the fact that good risks are "penalized" with a higher premium in the same way as bad risks when they report an accident.

If the predictions about the future technological development are correct, and given that even today black boxes are increasingly often built into vehicles by automobile producers,[12] one can pose the question if and how insurers will make use of black boxes for designing insurance contracts and what consequences this will have for the insureds and for social welfare. From the literature on information theory the second-best contracts which are established under asymmetric information are known to be self-selecting under adverse selection and an incentive compatible contract under moral hazard. We examine a setting in which the insurer has the technical opportunity of offering *in addition to* the second-best contracts an optional contract with ex post revelation of perfect information which only takes place when an accident has occurred. With the insureds having the right to choose among all these alternative contracts the question arises, which contracts will finally persist in equilibrium in the market and what implications this will have for insureds, insurers and total welfare. We analyze these problems for moral hazard and adverse selection separately as well as both for perfect competitive and monopolistic markets. Another important issue which we address is how privacy concerns, when taken into account, will affect our results.

The organization of the paper is as follows: Section 2 presents the general setting of the insurance model. Section 3 deals with the problem of adverse selection under perfect competition. First, we look at the referential situation when risk type is public information (3.1). Then the situation with risk type being private information and the resulting loss of social welfare is discussed (3.2). Finally, the situation in which insurers are able to offer contracts that include a clause for contingent accession to the black box is analyzed (3.3). Since, in this context, the problem of privacy loss becomes of considerable

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[11] For a detailed discussion on imperfect categorization see Hoy (1992, 322).

[12] E.g. Newstarget network; Spiegel – Online.

concern, we discuss possible reasons for and the consequences of having an aversion against the revelation of privacy (3.4). Adverse selection under monopoly is discussed in section 4 basically following the same pattern of thought as the previous section. Then the problem of moral hazard is briefly presented in the same framework, assuming monopoly first in section 5, and then assuming perfect competition in section 6. Section 7 concludes.

2 General setting of the model

The purpose of the model is to present the negative social effect of asymmetric information as is commonly known from the information literature and then, under the assumption that a black box reveals perfect information, to show that the first-best situation as with symmetric information can be restored if the insurer is able to include a clause in the contract, which allows him to access the black box after an accident has occurred and use the information to infer on the risk of the particular insured. In terms of adverse selection this would mean that the review of the data would reveal some characteristics related to the risk type of the insured like concentration, the quickness of reactions, or the driving competence as a whole. Concerning the problem of moral hazard the black box could disclose some evidence on the exerted effort contributing to a reduced risk of accident. Specifically it is assumed that a black box reveals perfect information about the risk type of the driver and about his behavior respectively, and that no costs are incurred thereby. The insurers are risk-neutral and all drivers are risk-averse with the same utility function, constant absolute risk aversion and an initial wealth of W. The possible damage is denoted by L, with $W > L$. A particular insurance contract is described by the insurance premium r and the coverage d. It is also assumed that if the insureds are indifferent between two contracts they take that one which is preferred by the insurer.

The possibility of offering different levels of coverage is justified when looking at the automobile insurance markets: even though the leeway of insurers is restricted through a regulation which prescribes a minimum coverage in third party liability insurance, firms do offer an alternative higher one, and in comprehensive insurance there are often several deductibles from which the insured can choose. Concerning the freedom of setting the insurance premiums there are no legal restrictions since the deregulation in 1994. Insurance premium adjustments, which would require a multi-period dynamic analysis, are completely ignored, but for the purpose of the model this should not be crucial. Another feature which is neglected in the model is the legal obligation to enter into a contract. If accounted for in the model, this regulation would mainly afflict the insured, since a given insurer may still get rid of a particular bad risk very quickly

whereas a customer would get with each insurer nearly the same conditions.[13] The alternative to insurance then would not be to drive without insurance, but to forego the possession of an own vehicle which would change the reservation utility. Still, for the conclusions of the model this is immaterial.

3 Adverse selection under perfect competition

When concentrating on the two contract variables mentioned above (d, r) (and thus ignoring the fact that insurers differentiate through various additional services) and considering the great number of firms in the market for automobile insurance, the assumption of perfect competition seems an appropriate one. Further it is assumed that there are two risk types of drivers - low risk (L) and high risk (H) with probability of accident $p^L \in (0,1)$ and $p^H \in (0,1)$, with $p^H > p^L$. All drivers know their own risk type with certainty. The proportion of the low risks in the population is q and all drivers have the utility function $u(w)$.

3.1 Symmetric information

In the referential situation with risk type being public information the optimal contracts are obtained with the insureds, each risk type separately, maximizing their expected utility under the zero-profit constraint of the insurers. The maximization problem for each risk type is therefore:

$$(1) \qquad \max_{r^{iK}, d^{iK}} p^i \cdot u(W - L - r^{iK} + d^{iK}) + (1 - p^i) \cdot u(W - r^{iK})$$

$$\text{s.t.} \qquad r^{iK} - p^i \cdot d^{iK} \geq 0, \qquad\qquad i = L, H$$

The resulting contracts are $C^{iK}(d^{iK}, r^{iK}) = (L, p^i \cdot L)$. The indemnity covers the whole loss, so that the risk-neutral insurers take on the whole risk and for this the insureds pay the actuarially fair premium corresponding to their individual risk. These contracts are Pareto-optimal. In the state-preference diagram (see Fig. 1) the axes represent the net wealth in case of an accident (A) and in case of no accident (NA). O_P represents the contingent wealth position without insurance. The optimal contracts are found as the tangency points between the indifference curves of the insureds and the respective zero-

[13] This is true under perfect competition. In fact, different insurance companies do offer slightly differing premiums for one and the same risk class, which is explained by their service differentiation through characteristics other than coverage. Therefore and because of the large number of insurers the automobile insurance market could be characterized as monopolistic competition.

profit lines of the insurers with slopes corresponding to the accident probabilities $-(1-p^i)/p^i$. As can be seen, these tangency points lie on the certainty line of the insureds meaning complete insurance.

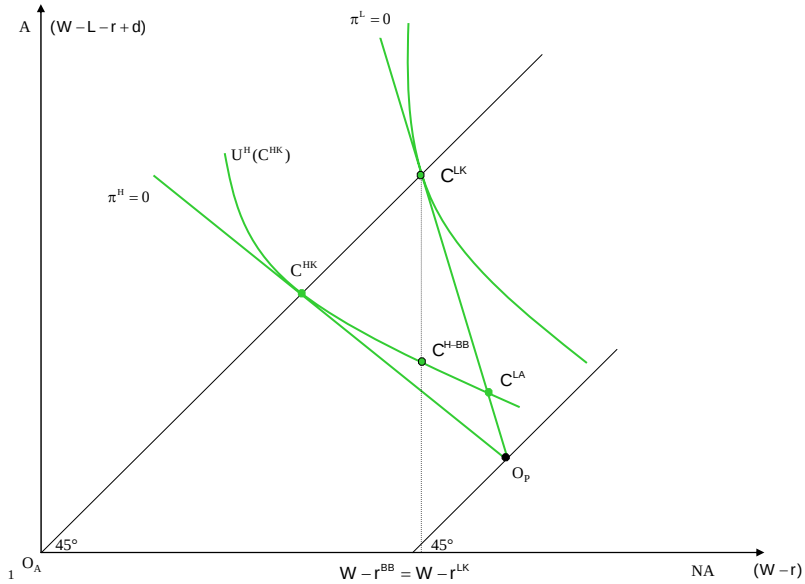

Figure 1: Adverse selection, perfect competition, RS

3.2 Asymmetric information

In case that the risk type is private information the contract set just found cannot persist, since the high risks will choose the contract designed for the low risks, thus leading to negative profits.

The equilibrium contracts under perfect competition and asymmetric information may differ depending on which equilibrium concept is chosen. For the Rothschild / Stiglitz (1976) equilibrium (denoted as RS) it is assumed that firms follow pure Nash-strategies with each firm considering the behavior of its rivals as fixed and making its own decisions without anticipating any reactions of the other firms. As a consequence of this assumption, a contract set can constitute an equilibrium, only if every single contract earns zero profits. With that no cross-subsidization from low risks to high risks is possible.[14] Another consequence is that a pooling equilibrium cannot exist.[15] It can be shown that for every given pooling contract C^P there is another contract C^T, which will be

[14] See Rothschild / Stigtlitz (1976, 643 f.) for an explanation.

[15] Rothschild / Stiglitz (1976, 634 f.).

preferred by the low risks, rejected by the high risks and earn strictly positive profits for the insurer if offered, which means that C^P cannot be an equilibrium.[16] Hence, if there is an equilibrium, it must be a separating one.

In order to determine the optimal contracts under asymmetric information the firm has to ensure that the high risks will not choose the contract for the low risks. The reverse will not happen, since low risks are strictly worse off when choosing the first-best contract for high risks C^{HK}. So C^{HK} will remain in the equilibrium set.[17] The contract for the low risks is determined by adding a self-selection constraint for the high risk type H

$$(2) \qquad u(W - r^{HK}) \geq p^H \cdot u(W - L - r^L + d^L) + (1 - p^H) \cdot u(W - r^L)$$

to the maximization problem (1) for $i = L$. Both constraints are binding so that graphically the optimal contract C^{LA} is found as the intersection between the low-risk zero-profit line and the high-risk indifference curve passing through C^{HK} (see Fig. 1). High risks are no worse off under asymmetric information while low risks buy only partial insurance and therefore suffer a loss of utility. Hence, the information asymmetry causes a loss of welfare.

A separating equilibrium may not exist under the assumptions made. Intuitively this may be the case when an imaginary alternative pooling contract seems relatively attractive. According to Rothschild / Stiglitz (1976, 637) this applies when high risks are too few, or if the probabilities of accident are only weakly apart, or if the risk aversion of the insureds is too high. A smaller proportion of high risks corresponds to lower costs of pooling to the low risks - with an imaginary pooling contract they would have to subsidize only a few high risks. The same is true for just weakly differing probabilities of accident which would imply relatively low subsidies per high risk. Finally, higher risk aversion implies higher costs for the low risk type of partially taking over the risk and hence higher costs of self-selection.

Since an equilibrium may not always exist on the one hand and on the other hand, since the assumptions made do not allow for cross-subsidization from low risks to high risks,

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16 Rothschild / Stiglitz (1976, 633) define equilibrium as a set of contracts such that, when the insureds choose among them to maximize expected utility „(i) no contract in the equilibrium set makes negative expected profits; and (ii) there is no contract outside the equilibrium set that, if offered, will make nonnegative profits“.

17 It can be shown that a self-selection constraint for type L is not binding so that the maximization problem for the high risk corresponds to the public information case (1). (see i.e. Dionne / Doherty / Fombaron (2000, 206-208)).

which is sometimes suggested by empirical evidence[18], the RS Nash equilibrium concept may be insufficient for explaining the automobile insurance market. Therefore one can resort to the Wilson-Miyazaki-Spence (WMS) equilibrium concept, for instance, which assumes anticipatory behavior of the firms, such that firms consider the other firm's reactions.[19] In this case a set of contracts is said to be an equilibrium if there is no other contract set "outside the equilibrium set such that, if offered, would earn a non-negative profit even after the unprofitable [contracts] in the original set have been withdrawn"[20]. For a sufficiently high proportion of high risks $(1-q)^{WMS}$ it corresponds to the RS equilibrium and otherwise it implies separating contracts with cross-subsidization. The equilibrium contract set (C^{HS}, C^{LS}) in the latter case is depicted in Fig. 2. In this figure, even though a RS equilibrium exists (the pooled zero-profit line $\pi^P = 0$ does not cut the low-risk indifference curve through C^{LA}), the social welfare is improved through moving from the RS equilibrium to the cross-subsidizing contracts: the insurers still have zero total profits, but both high and low risks get on higher indifference curves. Hence, in this case the RS equilibrium is not "second-best efficient". According to Dionne / Doherty / Fombaron (2000, 212) a RS equilibrium is second-best efficient[21], if and only if the proportion of high risks $(1-q)$ is higher than some critical value $(1-q)^{WMS}$ which is itself higher than the critical value $(1-q)^{RS}$ needed for the existence of an RS separating equilibrium.[22]

Rothschild / Stiglitz (1976, 644) derive the critical value $(1-q)^{WMS}$ from the optimal subsidy problem:

$$(3) \qquad \max_{d^{LA},s} \; p^L \cdot u(W - r^{LA} - L + d^{LA} - t) + (1-p^L) \cdot u(W - r^{LA} - t)$$

$$\text{s.t.} \qquad u(W - r^{HK} + s) \geq p^H \cdot u(W - r^{LA} - L + d^{LA} - t) + (1-p^H) \cdot u(W - r^{LA} - t)$$

$$s \geq 0,$$

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18 For his empirical research of the French automobile insurance market Dionne (2001, 20), for instance, considers cross-subsidization from low to high risks as a characteristic of this market. In contrast, Puelz / Snow (1994) find that there is no such cross-subsidization.

19 See Dionne / Doherty / Fombaron (2000, 209-212). Specifically the firms are assumed to have „Wilson foresight" which means that „no firm will offer one or more contracts that, although initially earning nonnegative profits, will cause other firms to withdraw their policies, with the result that the initial firm earns negative profits" (Hoy (1982, 322)).

20 Crocker / Snow (1985, 213).

21 "An allocation is second-best efficient if it is Pareto-optimal within the set of allocations that are feasible and the zero-profit constraint on the portfolio" (Dionne / Doherty / Fombaron (2000, 211)).

22 See also Crocker / Snow (1985, 213).

with $r^{LA} = p^L \cdot d^{LA}$. $t = (1-q) \cdot s / q$ is the "tax" that each low risk has to pay and s is the subsidy that each high risk receives. If the constraint $s \geq 0$ is binding, then the second-best efficient contract set is the RS equilibrium without subsidy and in this case it holds:

$$\frac{(1-q)^{WMS}}{q^{WMS}} > \frac{u'(W - p^H \cdot L) \cdot \left[u'(W - L - r^{LA} + d^{LA}) - u'(W - r^{LA}) \right]}{u'(W - r^{LA}) \cdot u'(W - L - r^{LA} + d^{LA})} \cdot \frac{p^L \cdot (1 - p^L)}{p^H - p^L}.$$

Formally the optimal contracts in Fig. 2 can also be found by maximizing the expected utility of the low-risks under the incentive compatibility constraint of the high risks and the zero-*total*- profit constraint[23]:

(4) $$\max_{r^{LS}, d^{LS}, r^{HS}, d^{HS}} p^L \cdot u(W - r^{LS} - L + d^{LS}) + (1 - p^L) \cdot u(W - r^{LS})$$

s.t. $$p^H \cdot u(W - r^{HS} - L + d^{HS}) + (1 - p^H) \cdot u(W - r^{HS}) \geq p^H \cdot u(W - r^{LS} - L + d^{LS}) + (1 - p^H) \cdot u(W - r^{LS})$$

$$q \cdot (r^{LS} - p^L \cdot d^{LS}) + (1 - q) \cdot (r^{HS} - p^H \cdot d^{HS}) \geq 0$$

The outcome is full insurance for high risks with a better than fair premium. Compared to the RS equilibrium low risks have to pay more than their fair premium but they receive a greater coverage now, which eventually makes them better off.

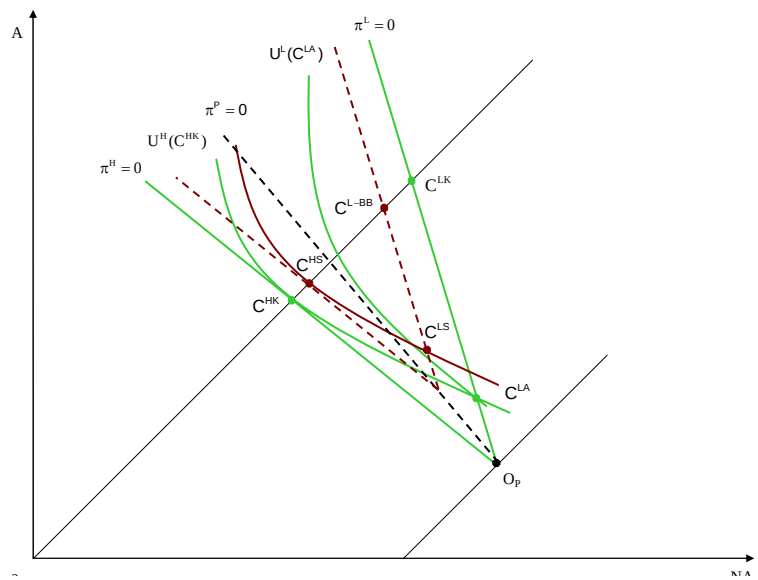

Figure 2: Adverse selection, perfect competition, WMS

23 See Crocker / Snow (1985, 209-211).

3.3 Contract with a clause for black box accession

Now it is assumed that the insurer has the possibility of offering a contract that permits him accession to the data collected by the black box, provided that an accident has occurred, and that he hereby obtains perfect information about the risk type of the particular driver. If an accident does not occur, the insurer cannot know what risk type has taken the contract, hence he can differentiate only through the indemnity he pays after the accident, but not through the insurance premium. Starting with the RS equilibrium, it is obvious that the good risks, who are made worse off by the information asymmetry, would be willing to reveal their risk type if they were given a chance to do so. Therefore, the insurer can now offer a contract including the clause for contingent accession to the black box C^{BB}, which is intended for low risks and corresponds to their first-best contract C^{LK}, i.e. it offers full coverage, but this is only paid after the insurer verifies that the driver is really a low risk. Concerning the bad risks, the insurer has to prevent their preferring this contract C^{BB} to their first-best contract C^{HK}. This is achieved by determining the coverage d^{H-BB}, in case that the driver turns out to be a high risk in such a way, that it satisfies the new self-selecting constraint of the high risk type:

(5) $$u(W - p^H \cdot L) = p^H \cdot u(W - L - p^L \cdot L + d^{H-BB}) + (1 - p^H) \cdot u(W - p^L \cdot L)$$

Graphically, the contract $C^{BB}(d^{LK}, d^{H-BB}, r^{LK})$ can be seen in Fig. 1. In fact, it consists of two separate wealth positions which are contingent on risk type: $C^{LK}(d^{LK}, r^{LK})$ if low risk, and $C^{H-BB}(d^{H-BB}, r^{LK})$ if high risk. Yet, in both contingent wealth positions the insurance premium and hence the net wealth in the case of no accident (NA) is identical. Now, with the possibility of ex post observation the first-best situation (C^{HK}, C^{LK}) is actually achieved. At the same time this is a Pareto-improvement in comparison to the previous contract set (C^{HK}, C^{LA}). It also follows that under the assumptions made, verification in that state only, in which the claim against the insurer arises, is sufficient, thus making continuous observation of driving behavior unnecessary.

The situation is a little bit different when considering a WMS equilibrium with cross subsidization. As can be seen in Fig. 2 bad risks are better off with the information asymmetry than with their first-best contract. So, they would resist to the introduction of the contract with a check-up, if they had some influence on that. However, the assumption, that firms possess Wilson's foresight, which is actually the prerequisite for a WMS equilibrium, *and* the assumption that the black box reveals perfect information, imply that equilibrium contracts *will* evolve to the first-best contracts C^{HK} and C^{BB} (which is in effect C^{LK}). This makes low risks better off (they get C^{LK} instead of C^{LS})

and high risks worse off (they get C^{HK} instead of C^{HS}), so that no Pareto-improvement takes place. One can ascertain that, under the assumptions made, only the contract set (C^{HK}, C^{LK}) fulfills the requirements for a WMS equilibrium[24].

Still, it would be possible to have a Pareto-improvement in comparison to the contract set C^{HS} and C^{LS}, if firms continued offering the contract C^{HS} (instead of switching to C^{HK}) for high risks while offering a contract with a clause for contingent accession to the black box

$$C^{BB-S} = \begin{cases} C^{L-BB-S}(L, r^{L-BB-S}), & \text{if type L} \\ C^{H-BB-S}(d^{H-BB-S}, r^{L-BB-S}), & \text{if type H} \end{cases}$$

in addition to it (in Fig. 2 only C^{L-BB-S} is depicted), with which total profits are just equal to zero. Again the indemnity d^{H-BB-S} in case that a high risk takes the contract with the stipulated accession to the black box must be determined such that high risks continue choosing C^{HS}. In this way high risks are no worse off than with asymmetric information. The insurers still make zero total profits.[25] Low risks indeed continue subsidizing high risks, yet they are better off because of receiving complete insurance now.

One can ascertain, that this contract set will not be an equilibrium under the assumptions made, since there exists another contract set (e.g. C^{HK}, C^{BB}) which, when offered, will make the original contract set (C^{HS}, C^{BB-S}) unprofitable and earn non-negative (zero) profits even after the unprofitable contract set is withdrawn. Hence, the contract set (C^{HS}, C^{BB-S}) could only persist with regulation.

What has just been shown to be Pareto-improving contracts is already applied in practice. Progressive Insurance Corp. offers alternatively to its former contracts a new contract including the so-called “TripSensor”. With this device insureds can collect data about their driving behavior and submit it periodically to the insurer. Progressive promises, that regardless of how unfavorable the submitted data are, only premium decreases (in the range of 5-25%) are possible after signing the TripSense contract. Insofar, provided that this promise is really held, these contract conditions are not a good example in support of the WMS equilibrium, implying that there is either no cross-subsidization

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24 See Hoy (1982, pp. 331-336) for an analysis of WMS equilibria when imperfect information on risk type is available to insurers.

25 As can be seen in Fig. 2 the contract designed for low risks C^{L-BB} lies on the same (dashed) iso-profit line as the initial contract C^{LS}. This means, that the subsidy per high risk has not changed, so that the total profit of the insurers is still equal to zero.

between contracts or no Wilson foresight between firms. It is also interesting to notice, that Progressive offers additional discounts merely for signing up this contract and then each time for just submitting the data.[26] One possible reason might be the attempt to compensate the insureds for their loss of privacy.

3.4 Privacy

The very thought of using black boxes inevitably raises the question of privacy. There might be two prominent reasons for insureds to dislike being observed: the first reason might be the intrinsic disutility from revealing personal data and the second reason the utility loss related to premium risk. The considerations below pertain to the RS equilibrium.

Concerning the first reason, one can imagine that the disutility from the revelation of personal data is an additional component $g(BB)$ to the already existing utility function $u(w)$ which is *subtracted* from it in case that the black box is reviewed. It is assumed that some proportion k of the low risks (denoted below as k-type low risks) suffers such a disutility when personal data are revealed. Thus, a utility function of $U(w, BB) = u(w) - g(BB)$ is generated in this state of nature. Further it is assumed that the rest of low risks (denoted below as $(1-k)$-type low risks) don not mind being observed: their utility function remains $u(w)$ whether or not a black box is used, i.e., it is completely independent of the application of a black box per se. One can easily ascertain that (i) the contract set C^{HK} and C^{BB} resulting in 3.3 (see Fig. 1) will persist, if the k-type low risks still prefer C^{BB} to C^{LA}, i.e., if $EU^L(C^{LK}) - p^L \cdot g(BB) > EU^L(C^{LA})$; (ii) all three contracts C^{HK}, C^{LA} and C^{BB} will persist in equilibrium, if the disutility from the revelation of data is so high, that k-type low risks prefer the second-best contract, that is if $EU^L(C^{LK}) - p^L \cdot g(BB) < EU^L(C^{LA})$. Indeed, if k-type low risks choose the contract including the clause for contingent accession to the black box, they will suffer an expected disutility from the revelation of personal data per se amounting to $-p^L \cdot g(BB)$, since only in case that an accident occurs (with a probability of p^L) the review of the black box and the disutility following from this $-g(BB)$ will take place. At the same time, however, this contract with contingent accession to the black box in effect results in the first-best contract C^{LK} offering full insurance and therefore, as was formerly shown, a higher expected utility. Therefore, k-type low risks have to trade off these two effects. In the former case the additional expected utility from having complete insurance is sufficiently high in order to compensate the expected disutility from

[26] Progressive Insurance Corp.

revealing personal data. Thus, besides the $(1-k)$-type low risks, for whom nothing has changed compared to 3.3, k-type low risks will also choose the contract C^{BB}. As before, high risks take their first-best contract C^{HK}. In contrast, in the latter case the expected disutility $-p^L \cdot g(BB)$ is so high, that it outweighs the benefits from receiving complete insurance. Hence it restrains the k-type low risks from choosing the contract with contingent accession to the black box. They prefer the second-best contract C^{LA}. Of course, $(1-k)$-type low risks continue preferring C^{BB} and high risks C^{HK}, so that in this case the equilibrium set consists of all three contracts.

It follows that, unless there are only k-type low risks in the population ($k=1$) who, in addition, suffer such a great disutility from the revelation of personal data, that they prefer the second-best contract (i.e. $EU^L(C^{LK}) - p^L \cdot g(BB) < EU^L(C^{LA})$), there will always be a Pareto-improvement of social welfare, when a contract with contingent accession to the black box C^{BB} is offered. In other words, if there is just one low risk who eventually prefers this contract, the total effect on social welfare will be positive.

Premium (or classification) risk arises when the insured does not know his own risk type with certainty and, by agreeing to a check-up, incurs the additional risk (i.e. apart from the risk of accident) of turning out to be one of either types, i.e. the risk of being charged a higher premium if the outcome is "high risk type". There is plenty of literature on risk categorization, which is often related to genetic testing in health insurance. For instance it is shown that the social and private (i.e. to the insureds) value of costless additional information on risk type is negative if it is public[27] or if it is private with insurers, however, being able to observe the information status of the agents[28]. Here it is not the objective to provide an overview of the theory on risk classification.[29] Just an exemplary possible case will be presented in order to demonstrate, that in the presence of uncertainty about risk type, the readiness of the customers to choose the contract with a clause for contingent accession to the black box might be reduced.

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27 Doherty / Posey (1998, pp. 194-196).

28 Doherty / Thistle (1996, 85, 88).

29 The articles on this topic analyze various scenarios depending on whether the additional information that can be obtained is public or private, whether the insurers can observe the information status of the agents, whether the agents can decide if to reveal the contents of the additional information, whether they have a priori knowledge concerning their risk type etc. (see e.g. Crocker / Snow (2000), Crocker / Snow (1992), Crocker / Snow (1986), Hoy (1982), Doherty / Thistle (1996), Doherty / Posey (1998)).

It is assumed that there are informed low risks (*L*), informed high risks (*H*) and uninformed people (*U*). It is common knowledge that the uninformed might be good risk with a probability of q. From the viewpoint of the insurers there are three types of drivers, so that the equilibrium contracts, provided that equilibrium exists, are C^{HK}, C^{U}' und C^{LA}' (see Fig. 3) with the self-selecting constraints holding for type *H*:

(6) $$u(W - p^H \cdot L) = p^H \cdot u(W - L - p^U \cdot d^U{}' + d^U{}') + (1 - p^H) \cdot u(W - p^U \cdot d^U{}')$$

and for type U:

(7) $$p^U \cdot u(W - L - p^U \cdot d^U{}' + d^U{}') + (1 - p^U) \cdot u(W - p^U \cdot d^U{}') =$$

$$p^U \cdot u(W - L - p^L \cdot d^{LA}{}' + d^{LA}{}') + (1 - p^U) \cdot u(W - p^L \cdot d^{LA}{}'),$$

where $p^U = q \cdot p^L + (1-q) \cdot p^H$

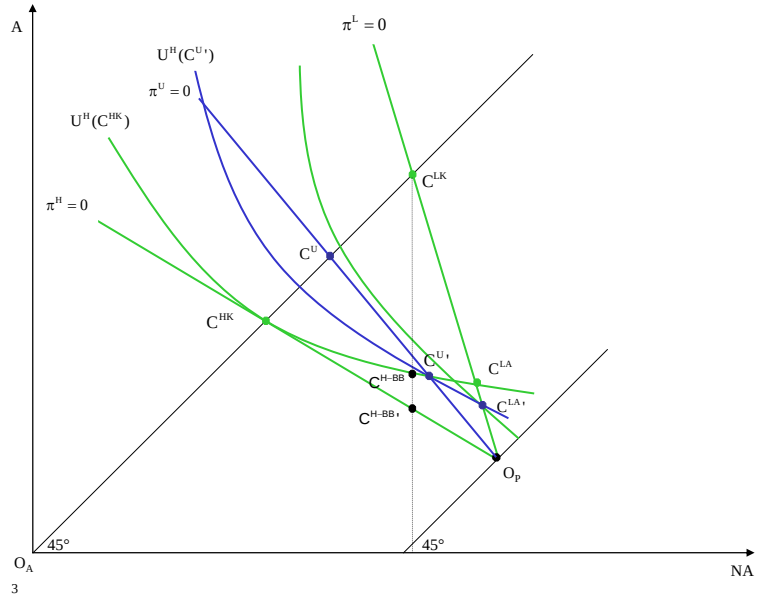

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Figure 3: Adverse selection, privacy concerns

As is shown in the figure, good risks are worse off in the presence of uninformed people [$EU^L(C^{LA}{}') < EU^L(C^{LA})$] since now they have to differentiate from both *H* and *U* risk types by partially assuming the risk of accident. Now, the insurer who considers offering contracts with contingent accession to the black box has two alternative choices: the first one is to offer such a contract that is originally intended only for low risks. The contract from 3.3 C^{BB} (with wealth position C^{H-BB}, if high risk) will not discourage the uninformed from choosing it since in comparison to the high risk drivers they still have a chance of turning out to be low risks, hence there is a greater probability of the

better outcome $(W - r^L)$. Since their taking the contract from 3.3 would imply a loss to the insurer, a stronger self-selecting constraint for the uninformed must be set. Hence, the corresponding coverage must satisfy:

$$(8) \qquad p^U \cdot u(W - L - p^U \cdot d^U{}' + d^U{}') + (1 - p^U) \cdot u(W - p^U \cdot d^U{}') =$$

$$(1-q) \cdot p^H \cdot u(W - L - p^L \cdot L + d^{HU-BB}) + [(1-q) \cdot (1 - p^H) + q] \cdot u(W - p^L \cdot L)$$

So the indemnity necessary to just prevent both uninformed (*U*) and informed high risks (*H*) from choosing the contract with black box will be d^{HU-BB}.[30] Thus, uninformed drivers will remain so and only the low risks will agree to a contract with contingent accession to the black box.

The second alternative to the insurer, provided that competitive pressure will cause the contract offered $C^{BB}{}'$ to end up in the contingent wealth position C^{LK} (with the insurance premium $p^L \cdot L$) for informed low risks, would simply be to set the indemnity for the case that the driver turns out to be a high risk in a way that ensures zero-profits, no matter if informed high risks or uninformed take the contract. In Fig. 3 this implies the wealth position $C^{H-BB}{}'[(p^L / p^H) \cdot L,\ p^L \cdot L]$ contingent on the driver's turning out to be a high risk. All low risks (*L*) will choose the contract with contingent accession to the black box; all high risks (*H*) will deny it. The question is, what the uninformed (*U*) drivers will do. Following the model of Doherty / Thistle (1996, 92 f.), it is assumed first, that all insurers expect the uninformed to become informed (i.e., to choose the contract with contingent accession to the black box). In this case they will offer the contract set

$$C^{HK} \text{ and } C^{BB}{}' = \begin{cases} C^{LK}(L,\ p^L \cdot L), & \text{if type L} \\ C^{BB}{}'(\frac{p^L}{p^H} \cdot L,\ p^L \cdot L), & \text{if type H} \end{cases}.$$

Should the uninformed really get informed, then they will have an expected utility of

$$(9) \qquad \begin{aligned} EU^U(C^{BB}{}') &= q \cdot EU^L(C^{LK}) + (1-q) \cdot EU^H(C^{H-BB}{}') = q \cdot u(W - p^L \cdot L) + \\ &(1-q)\left[p^H \cdot u(W - p^L \cdot L - L + (p^L / p^H) \cdot L) + (1 - p^H) \cdot u(W - p^L \cdot L) \right] \end{aligned}$$

If they, in contrast, deny the contract $C^{BB}{}'$, i.e. decide to remain uninformed, they will either have to take the contract C^{HK} with an expected utility of $E^U(C^{HK}) = u(W - p^H \cdot L)$ or remain without insurance with the reservation utility

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30 It can be shown, that when the self-selecting constraint for type *U* holds, then the self-selecting constraint for type *H* also does.

$\underline{U}^U = p^U \cdot u(W-L) + (1-p^U) \cdot u(W)$. Therefore, the value of the additional information, i.e. the value to the uninformed driver of choosing the contract with contingent accession to the black box, is:

(10) $I^* = q \cdot EU^L(C^{LK}) + (1-q) \cdot EU^H(C^{H-BB}') - EU^U(C^{HK})$ or

(11) $I^* = q \cdot EU^L(C^{LK}) + (1-q) \cdot EU^H(C^{H-BB}') - \underline{U}^U$, respectively. Only if this is positive ($I^* > 0$), will the uninformed choose the contract with the clause for contingent accession to the black box.

If the insurers expect the uninformed *not* to get informed, they will offer the contract set C^{HK}, C^U' and C^{BB}'. In this case the value of getting informed through choosing the contract with black box accession is

(12) $I^{**} = q \cdot EU^L(C^{LK}) + (1-q) \cdot EU^H(C^{H-BB}') - EU^U(C^U')$

which is, after some transformation, equivalent to

(13) $I^{**} = q \cdot \left[EU^L(C^{LK}) - EU^L(C^U') \right] + (1-q) \cdot \left[EU^H(C^{H-BB}') - EU^H(C^{HK}) \right]$

Should this be positive, i.e.,

$$I^{**} > 0 \quad \Leftrightarrow \quad \frac{q}{1-q} > \frac{EU^H(C^{HK}) - EU^H(C^{H-BB}')}{EU^L(C^{LK}) - EU^L(C^U')},$$

then the uninformed drivers will choose to get informed and take the contract with contingent accession to the black box, so that in this case the contract set C^{HK}, C^U' and C^{BB}' cannot be an equilibrium.

Since $EU^U(C^U') > EU^U(C^{HK})$ [and $EU^U(C^U') > \underline{U}^U$, respectively], it follows from (10) [and (11), respectively] and (12) that $I^{**} < I^*$. Only if $0 < I^{**} < I^*$, will the uninformed drivers choose to get informed, so that the equilibrium contracts will be C^{HK} and C^{BB}'. If $I^{**} < I^* < 0$, the uninformed will deny the contract with contingent accession to the black box so that the equilibrium contract set will be C^{HK}, C^U' and C^{BB}'. This will also happen if $I^{**} < 0 < I^*$: given that only the contracts C^{HK} und C^{BB}' are offered, the uninformed will choose C^{BB}'; given that the contract set C^{HK}, C^U' and C^{BB}' is offered, they will choose C^U'. So, if just one insurer offers C^U', provided that C^{HK} und C^{BB}' are initially on the market, all uninformed will take C^U' and thus deny C^{BB}'.

As can be seen, due to the classification risk, a contract with contingent accession to the black box is not automatically attractive to uninformed customers. Under certain circumstances the uninformed drivers will prefer to remain so.

Nevertheless, the inclusion of the black-box contract into the set of contracts makes no one worse off, but at the same time makes informed low risks (L) better off. Hence, since the clause for contingent accession to the black box gives low risks the opportunity to directly signal their risk type to the insurer without the necessity of taking over any risk, welfare is Pareto-improved.

4 Adverse selection under monopoly[31]

4.1 Symmetric information

In contrast to perfect competition this time the monopolist skims off the whole surplus of the contractual relationship so that the insureds just receive their reservation utility

(14) $\underline{U}^i = p^i \cdot u(W-L) + (1-p^i) \cdot u(W)$.

When risk type is public information the optimal contracts are found with the insurer maximizing his expected profit subject to the participation constraint of the insured:

(15) $\max_{r^i, d^i} r^i - p^i \cdot d^i$

s. t. $p^i \cdot u(W-L-r^i+d^i) + (1-p^i) \cdot u(W-r^i) \geq \underline{U}^i, \quad i = L, H,$ (RC-i),

The resulting contracts C^i* are first-best and imply complete insurance $d^i* = L$ and an insurance premium of $r^i* = p^i \cdot L + z_i$ consisting of the actuarially fair premium and the profit per insured z_i. This is also the risk premium of type i that he is willing to forego in order to move from the state without insurance O_P to complete insurance in C^i* (see Fig. 4). As can be seen in the figure, the indifference curves corresponding to the reservation utility pass through the state without insurance O_P, and C^i* are the certainty equivalents on these curves.

[31] This case is presented very briefly, for a detailed discussion see the seminal work of Stiglitz (1977).

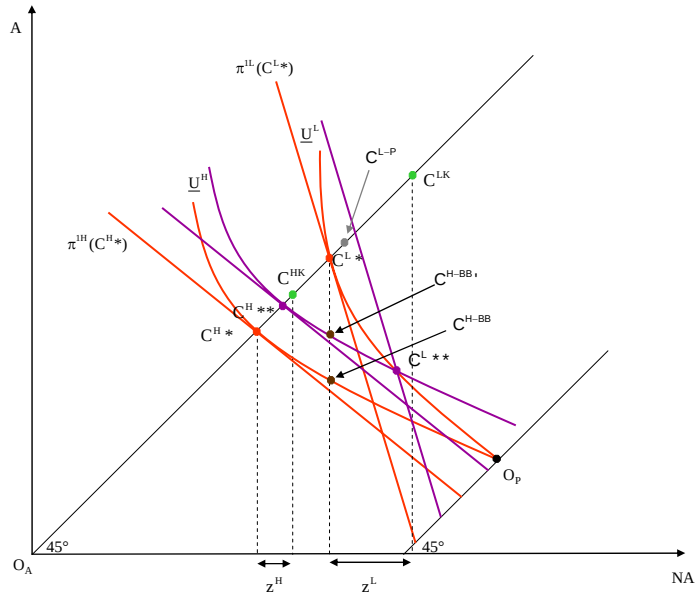

Figure 4: Adverse selection, monopoly

4.2 Asymmetric Information

When risk type is private information the insurer will not offer the first-best contracts any more, since both low and high risks will choose C^L*, thus significantly reducing profits. Stiglitz (1977, 417-421) shows that the insurer will either offer self-selecting contracts, or he will offer an insurance contract only to the high risks, letting low risks uninsured.[32] Unlike the situation with perfect competition the exact position of the self-selecting contracts - if they exist - depends on the proportions of risk types. In order to determine these second-best contracts C^H** and C^L**, the monopolist has to reduce the indemnity paid on the low risk contract so that it becomes unattractive to high risks. Formally this is accomplished through maximizing the total expected profit, subject to the participation constraints and the incentive compatibility constraints of both risk types:

$$\text{(16)} \qquad \max_{r^{L**},d^{L**},r^{H**},d^{H**}} \quad q\cdot(r^{L**}-p^L\cdot d^{L**})+(1-q)\cdot(r^{H**}-p^H\cdot d^{H**})$$

$$\text{s.t.} \qquad p^L\cdot u(W-L-r^{L**}+d^{L**})+(1-p^L)\cdot u(W-r^{L**}) \quad \geq \quad \underline{U}^L \qquad \text{(IR-L)}$$

$$p^H\cdot u(W-L-r^{H**}+d^{H**})+(1-p^H)\cdot u(W-r^{H**}) \quad \geq \quad \underline{U}^H \qquad \text{(IR-H)}$$

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32 As in the case under perfect competition there is no pooling equilibrium (see Stiglitz 1977, 418-220, for a proof).

$$p^L \cdot u(W - L - r^{L**} + d^{L**}) + (1 - p^L) \cdot u(W - r^{L**}) \quad \geq \quad p^L \cdot u(W - L - r^{H**} + d^{H**}) + (1 - p^L) \cdot u(W - r^{H**}) \qquad \text{(IC-L)}$$

$$p^H \cdot u(W - L - r^{H**} + d^{H**}) + (1 - p^H) \cdot u(W - r^{H**}) \quad \geq \quad p^H \cdot u(W - L - r^{L**} + d^{L**}) + (1 - p^H) \cdot u(W - r^{L**}) \qquad \text{(IC-H)}$$

It can be shown that the participation constraint of the high risks (IR-H) is not binding (they get more than just reservation utility) and that it can be derived from the participation constraint of the low risks (IR-L) and the high risk incentive-compatibility-constraint (IC-H). Moreover, the low risk incentive-compatibility constraint (IC-L) is not binding so that the problem reduces to (16) subject to (IR-L) and (IC-H) which are both binding. When solving it one gets $d^{H**} = L$ meaning complete insurance of the high risks and the optimality condition

$$\text{(17)} \qquad \frac{1-q}{q} = \frac{u'(W - r^{H**}) \cdot \left[u'(W - L - r^{L**} + d^{L**}) - u'(W - r^{L**}) \right]}{u'(W - L - r^{L**} + d^{L**}) \cdot u'(W - r^{L**})} \cdot \frac{p^L(1 - p^L)}{p^H - p^L}.$$

The resulting contracts $C^H{**}$ and $C^L{**}$ are depicted in Fig. 4, with $C^L{**}$ implying partial insurance of low risks. The profit with high risks is reduced compared to the situation with symmetric information, but this is simply redistribution from the monopolist to the insureds: they now get some consumer surplus. In contrast, the monopolist's profit with low risks is reduced too, but they still just get their reservation utility. This is due to the suboptimal risk-allocation now with low risks demanding compensation for partially incurring the risk of accident, which eventually reduces the profit of the insurer. Hence the situation leads to loss of social welfare compared to the situation with symmetric information.

The same is true in case that there is no insurance of low risks[33]. As is shown by Stiglitz (1977, 421), there is a critical value for the proportion of high risks to low risks which, if exceeded, means that there is no separating equilibrium with high risks getting their first-best contract and low risks remaining without insurance, i.e., if

$$\text{(18)} \qquad \frac{1-q}{q} > \frac{u'(W - r^H{*}) \cdot \left[u'(W - L) - u'(W) \right]}{u'(W - L) \cdot u'(W)} \cdot \frac{p^L(1 - p^L)}{p^H - p^L}.$$

Clearly there is a loss of social welfare compared to the reference situation: both risk types have their reservation utility, the monopolist, however, has to forego his profit with low risks.

[33] This is a corner solution to the maximization problem (16) found with the Kuhn-Tucker conditions.

4.3 Contract with a clause for black box accession

In an analogous manner as with perfect competition the first-best situation can be restored, if it is possible for the insurer to include a condition, which permits him accession to the black box after an accident has occurred. Here too, the insurer can offer in addition to the first-best contract for high risks C^H* a contingent contract C^{BB} with insurance premium r^L* which offers full coverage, if the insured turns out to be low risk (i.e., it results in the first-best contract for the low risk C^L*) and a disadvantageous indemnity d^{H-BB}, in case that the insured turns out to be a high risk (i.e. it results in C^{H-BB}). d^{H-BB} must be set so that high risks choose the "right" contract C^H*, i.e., the incentive compatibility constraint

$$(19) \qquad u(W-r^H*) = \underline{U}^H = p^H \cdot u(W-L-r^L*+d^{H-BB}) + (1-p^H)\cdot u(W-r^L*)$$

must hold. Indeed, the resulting wealth positions are as in the referential situation C^H* and C^L* - there is optimal risk allocation, both risks types receive their reservation utility and the monopolist skims off the entire consumer surplus. Still, this is not a Pareto-type improvement, since high risks are worse off than before (with C^H** from 4.2). Though not a direct market outcome (since the monopolist has the whole bargaining power), a Pareto-type improvement would occur, if the monopolist were forced by regulation to continue offering C^H** instead of C^H*. In this case the wealth position for high risks which is required to just discourage them from choosing the black box contract will be $C^{H-BB}{}'$ in Fig. 4. Thus, the monopolist will increase his profits with low risks only, while both low and high risks will be made no worse off. This means a Pareto-type improvement of social welfare.

4.4 Privacy

Finally the question shall be addressed, what the outcome would look like, if there were a proportion k of low risks - denoted as k-type low risks - who dislike the disclosure of private information per se and suffer a disutility of $-g(BB)$ if this happens. For this purpose the corresponding assumptions which were made in the case of perfect competition apply. k-type low risks will never take the contract C^{BB}, since with it they would have less than reservation utility. Therefore the monopolist has basically three possibilities[34]: (i) to offer C^H* for high risks and a contract with contingent accession to the black box $C^{BB}_{if\,k}$, which results in a full insurance "pooling" contract C^{L-P} for both k-

[34] For all alternative cases the corresponding wealth position of the black box contract resulting for high risks, has to be derived so that it meets the incentive compatibility constraint of high risks. Below this is not mentioned explicitly.

type and $(1-k)$-type low risks. This contract can be designed so that it just meets the participation constraint of k-type low risks. Such a contract could be for instance C^{L-P} in Fig. 4 (ii) to offer a pair of self-selecting contracts for high risks $C^{H}_{if\,k}**$ and k-type low risks $C^{L}_{if\,k}**$ and in addition to that a black box contract resulting in $C^{L}*$ for $(1-k)$-type low risks, or (iii) to offer $C^{H}*$ for high risks, a black box contract resulting in $C^{L}*$ for $(1-k)$-type low risks and to leave k-type low risks without insurance, which is in fact a special case of (ii).

(ii) In presence of an alternative contract with contingent accession to the black box, the existence of k-type low risks will alter the position of the originally found self-selecting contract set $(C^{L}**, C^{H}**)$, since the particular self-selecting contracts depend on the proportions of risk types. The proportion of insureds who will now take the self-selecting contract with partial insurance is reduced from q to $q \cdot k$, since $(1-k)$-type low risks, who do not mind the disclosure of privacy, will prefer the contract with black box accession which results for them in the wealth position $C^{L}*$. Thus the proportion $q \cdot k$ has to be inserted for q in problem (16) in order to determine the new self-selecting contract set $(C^{L}_{if\,k}**, C^{H}_{if\,k}**)$. Accordingly, the optimality condition (17) also changes and so does the critical value (18). Then, provided that the proportions of risk types are such that

$$(20) \qquad \frac{1-q}{k \cdot q} > \frac{u'(W-r^{H}*) \cdot \left[u'(W-L)-u'(W)\right]}{u'(W-L) \cdot u'(W)} \cdot \frac{p^{L}(1-p^{L})}{p^{H}-p^{L}}$$

holds, k-type low risks will remain without insurance (iii) and the contracts offered will be $C^{H}*$ for high risks and C^{BB} ($C^{L}*$ effectively) for $(1-k)$-type low risks. Otherwise three contracts will be offered: a black box contract with wealth position $C^{L}*$ for $(1-k)$-type low risks and the new self-selecting contract set $(C^{L}_{if\,k}**, C^{H}_{if\,k}**)$ for k-type low risks and high risks respectively. Graphically, if the new self-selecting contract set exists, the contract $C^{H}_{if\,k}**$ will lie somewhere between the initial self-selecting contract for high risks $C^{H}**$ and the contract from the referential situation $C^{H}*$. Analogously $C^{L}_{if\,k}**$ will be situated somewhere between the initial self-selecting contract $C^{L}**$ and the position without insurance O_{P}. This immediately follows from the conditions for existence of self-selecting contracts (18) and (20). Since $(1-q)/k \cdot q > (1-q)/q$, it follows that if the critical value is greater than $(1-q)/k \cdot q$ then it is also greater than $(1-q)/q$ or in other words: if $C^{H}_{if\,k}**$ lies to the right of $C^{H}*$, then $C^{H}**$ will lie even more to the right.

(i) The other possibility for the monopolist is to offer the contract pair $C^{H}*$ and a black box contract $C^{BB}_{if\,k}$ with the wealth position $C^{L-P} = (L, r^{L-P})$ contingent on being low

risk, so that the latter is chosen both by $(1-k)$-type and k-type low risks. For this purpose low-risks who dislike the revelation of privacy have to be compensated for accepting the black box, i.e., the insurance premium r^{L-P} has to be set lower than $r^{L}*$ so that the participation constraint of k-type low risks just holds:

$$(21) \qquad u(W - r^{L-P}) - p^{L} \cdot g(BB) = \underline{U}^{L}$$

Of course, this also means that $(1-k)$-type low risks will receive strictly more than their reservation utility. The monopolist will make a profit strictly less than in the referential situation in which he knows the risk types from the outset. Still, the total profit of the monopolist *might* be increased compared to a situation when the contract with contingent accession to the black box is offered to k-type low risks only. In which one of both alternatives (i) or (ii) the insurer's profit will be higher depends on the particular proportion k and on the dimension of the disutility $-g(BB)$ caused by the implementation of a black box.[35]

Concerning social welfare the same arguments can be put forward as in the case of perfect competition and the WMS subsidizing equilibrium. Even if there are some insureds, who dislike the loss of privacy, there is a Pareto-type improvement of welfare when a contract with contingent accession to the black box is offered, as long as high risks are *not* made worse off than without it, i.e. as long as the monopolist is forced by regulation to continue offering $C^{H}**$. No matter if, depending on the particular expected profits, the monopolist then decides to offer a pooling contract C^{L-P} designed for both k-type and $(1-k)$-type low risks or if he decides to offer all three contracts $C^{H}**$ (for high risks), $C^{L}*$ (for $(1-k)$-type low risks) and $C^{L}**$ for k-type low risks, there is always a Pareto-type improvement compared to the situation without the existence of black boxes (4.2). This is due to the fact that at least $(1-k)$-type low risks (or even all low risks) are disburdened of the necessity for taking only partial insurance in order to signal their risk type. This can now be directly achieved through accepting the contract with contingent accession to the black box.

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35 The greater the proportion of low risks disliking the revelation of private data k and the smaller $g(BB)$, the more probable it is that the monopolist will make a higher profit with a pooling contract C^{L-P} for both k-type and $(1-k)$-type low risks (i).

5 Moral Hazard under Monopoly[36]

Now it is assumed that insureds no longer differ by their risk type but that they can influence the probability of accident through the exerted effort. There are only two possible effort levels – low e^W and high e^M effort with corresponding probabilities of accident $p(e^W) = p^W > p(e^M) = p^M$ with $p^i \in (0,1)$. The utility function $U(w,e) = u(w) - v(e)$ is separable in effort with $v(e^M) > v(e^W)$ being the disutility of effort.[37]

5.1 Symmetric Information

With two given effort levels, the insurer will maximize expected profits subject to the participation constraint of the insureds for a given effort level separately and then stipulate that one which brings about the higher expected profit. Formally the problem is:

$$(22) \qquad \max_{r^i, d^i} r^i - p^i \cdot d^i$$

$$\text{s.t.} \qquad p^i \cdot u(W - L - r^i + d^i) + (1 - p^i) \cdot u(W - r^i) - v(e^i) \geq \underline{U} \qquad i = W, M$$

It is assumed that the insured would exert the higher effort if having no insurance, so that[38]

$$(23) \qquad \begin{aligned} \underline{U} &= p^M \cdot u(W - L) + (1 - p^M) \cdot u(W) - v(e^M) \\ &> p^W \cdot u(W - L) + (1 - p^W) \cdot u(W) - v(e^W) \end{aligned}$$

and that $E\left[\pi(C^M)\right] > E\left[\pi(C^W)\right]$, so that the insurer will stipulate e^M. With effort being observable the risk allocation is efficient, meaning complete insurance (see C^M in Fig. 5).

5.2 Asymmetric Information

When effort level is unobservable the insurer will have to turn over part of the risk of accident to the insured in order to make him exert the higher effort. Formally this is achieved by adding to problem (22) for e^M the incentive compatibility constraint

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36 For a detailed discussion see Macho-Stadler / Pérez-Castrillo (2001, 35-46, 57-62).

37 With this specification the disutility of effort exerts an impact only on the exact position, but not on the slope of the indifference curves.

38 In Fig. 5 this is reflected by O_P lying on the indifference curve which represents the reservation utility and corresponds to the high effort (higher slope) $\underline{U}$ if e^M, while the indifference curve representing the same utility but low effort (lower slope) $\underline{U}$ if e^W lies above O_P.

$$(24)\quad \begin{aligned} & p^M \cdot u(W - L - r^{MA} + d^{MA}) + (1 - p^M) \cdot u(W - r^{MA}) - v(e^M) \\ & \geq p^W \cdot u(W - L - r^{MA} + d^{MA}) + (1 - p^W) \cdot u(W - r^{MA}) - v(e^W) \end{aligned}$$

Both constraints are binding and the optimal contract $C^{MA}(d^{MA}, r^{MA})$ is found as the solution of the system of both equations. Graphically this is the intersection between the indifference curve corresponding to the reservation utility and the higher effort level "$\underline{U}$ if e^M" and the curve "IC"[39], which represents all combinations of contingent wealth for which the incentive compatibility constraint is binding. Hence, indifference curves which correspond to different effort levels (i.e. probabilities and therefore have different slopes) but to the same utility must intersect on this line.

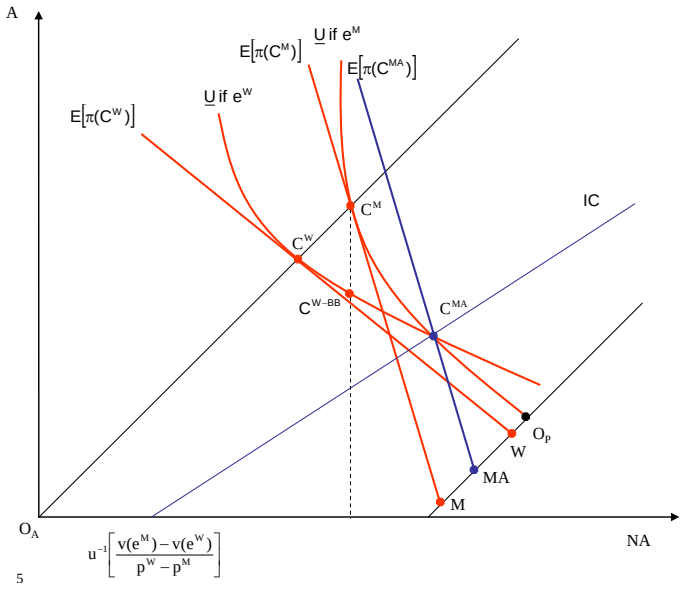

Figure 5: Moral hazard, monopoly

As can bee seen in Fig. 5 the insurer will offer the just established contract C^{MA} if the expected profit with it is higher than the expected profit when demanding low effort and thus offering C^W [40]. Compared to the situation with symmetric information the insured still has just his reservation utility, but the profit of the insurer has declined $E\left[\pi(C^{MA})\right] < E\left[\pi(C^M)\right]$. Again this is due to the inefficient risk-allocation causing a

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39 The IC-curve need not be a straight line. In Fig.5 it is depicted as such for simplicity. In all wealth positions above this curve the insured will choose the low effort e^W and below the curve he will choose the higher effort e^M.

40 C^W is found by solving the maximization problem (22) for the low effort level e^W, which is not affected by the information asymmetry. In Fig. 5 the intersection (MA) of the certainty line of the insurer with the iso-profit curve $E[p(C^{MA})]$ lies to the left of the intersection (W) with the iso-profit curve $E[\pi(C^W)]$ which means that C^{MA} is more profitable than C^W.

loss of welfare It might be the case that the insurer prefers to demand the low effort and offer C^W instead of C^{MA}, which is, though characterized by complete insurance, related with a reduction of profit $E\left[\pi(C^W)\right] < E\left[\pi(C^M)\right]$ too and hence with loss of social welfare.

5.3 Contract with a clause for black box accession

As with adverse selection the first-best situation is achieved when a contract is offered that allows accession to the black box contingent on having an accident. Hereby the monopolist can stipulate the higher effort e^M in the contract and cover the whole loss if the insured has really made this effort e^M, and pay a smaller indemnity d^{W-BB}, if he finds out that the insured has exerted low effort e^W. The particular value of the "penalizing" indemnity is determined by solving the incentive compatibility constraint for d^{W-BB}:

$$(25) \qquad p^W \cdot u(W - L - r^M + d^{W-BB}) + (1 - p^W) \cdot u(W - r^M) - v(e^W) = u(W - r^M) - v(e^M)$$

The contingent wealth of someone who would exert low effort is depicted in Fig. 5 as C^{W-BB} which lies on the indifference curve corresponding to the reservation utility $\underline{U}$ if e^W. Thus the insured will just choose the higher effort e^M.

6 Moral Hazard under perfect competition

6.1 Symmetric Information

Under perfect competition and free entry the insurers will earn zero profits and insureds will maximize their expected utility under the zero-profit constraint of insurers. Which effort level will persist this time depends upon which effort level will maximize the expected utility of the insureds. For this purpose the maximization problem

$$(26) \qquad \max_{d^i, r^i} \; p^i \cdot u(W - L - r^i + d^i) + (1 - p^i) \cdot u(W - r^i) - v(e^i)$$

$$\text{s.t.} \qquad r^i - p^i \cdot d^i \geq 0, \qquad i = W, M,$$

is solved for a given effort level, which results in complete insurance $d^i = L$ and the actuarially fair insurance premium $r^i = p^i \cdot d^i$. Then, with these values, the expected utility is compared. The exerted effort will be e^M, if $EU(C^M, e^M) > EU(C^W, e^W)$. This is depicted in Fig. 6. By the same argument for which indifference curves representing the same utility level cross on the IC-curve (see 5.2), higher utility is represented by indifference curves which intersect the IC-curve higher and more to the right. Therefore, in this figure, C^M is the equilibrium contract.

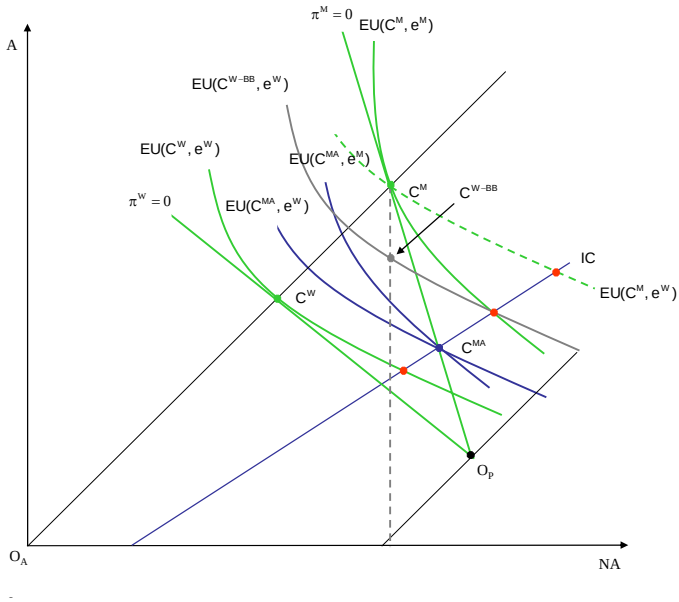

Figure 6: Moral hazard, perfect competition

6.2 Asymmetric Information

When effort is private information and provided that C^M is offered, insureds will maximize utility by exerting the low effort level e^W. In Fig. 6 the fact that $EU(C^M, e^W) > EU(C^M, e^M)$ is verified by the intersections of the corresponding indifference curve with the IC-curve. This will cause losses to the insurers so that C^M cannot persist in equilibrium. The incentive compatible contract C^{MA} is found through adding to problem (26) the incentive compatibility constraint:

$$(27) \quad \begin{aligned} & p^M \cdot u(W - L - r^{MA} + d^{MA}) + (1 - p^M) \cdot u(W - r^{MA}) - v(e^M) \\ & \geq p^W \cdot u(W - L - r^{MA} + d^{MA}) + (1 - p^W) \cdot u(W - r^{MA}) - v(e^W) \end{aligned}$$

Both constraints are binding so that in Fig 6. the optimal contract C^{MA} is found as the intersection of the zero-profit line $\pi^M = 0$ and the IC-curve. As can be seen it implies partial insurance. This time it is the insureds who are worse off: in order to "commit" to the higher effort they have to partially incur the risk of accident. Still, in this figure, choosing high effort is better than switching to the low effort level [$EU(C^{MA}, e^M) > EU(C^W, e^W)$]. However, also in case that low effort with C^W as the corresponding contract result, there would be a loss of social welfare because of $EU(C^w, e^W) < EU(C^M, e^M)$.

6.3 Contract with a clause for black box accession

Since with asymmetric information the insureds at any rate incur a loss of utility, they will have an interest to reveal their exerted effort to the insurer. Hence, provided that the contract with accession to the black box is (technically) viable, insureds will choose it. With such a contract they will be able to achieve the first-best wealth position C^M with complete insurance which maximizes their utility. In fact, the commitment to choose the higher effort is facilitated through the certain "penalty" of getting a smaller indemnity d^{W-BB} for the case that they should have chosen the low effort and have had an accident. Thus, compared to the situation without the possibility of reviewing the black box (6.2), there clearly is a Pareto-type improvement of welfare.

7 Concluding remarks

Inspired by the growing technical possibilities for observing driving behavior in ever increasing detail, we examined the consequences of insurers being able to obtain perfect information on risk type or behavior by reviewing the data from a black box after an accident has occurred. As was shown in the previous sections, provided that the black box reveals perfect information, the direct outcome will be the contracts from the referential situation with symmetric information, no matter if the problem of information asymmetry is adverse selection or moral hazard, or if it persists under perfect competition or monopoly. However, it was also shown that in those cases, in which high risks formerly received an information rent (namely in the cases of adverse selection under monopoly and adverse selection under perfect competition with cross-subsidization from low to high risks), high risks are made worse off when the new technological option is introduced. In these cases the black box does not automatically lead to a Pareto-type improvement of welfare. Still, even in those cases a contract with contingent accession to the black box can lead to a Pareto-type improvement if some regulation is introduced. When it ensures that high risks are not made worse off, there remain only the positive effects on social welfare from low risks receiving complete insurance.

Similarly the question of privacy loss was examined. It was shown that, as long as there are some people who don not mind the revelation of privacy, the black box will make them better off without making anyone worse off, so that there is again a Pareto-type improvement.

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