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Optimal Loss Financing under Bonus-Malus Contracts

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Abstract

The paper analyses the question: *Should an insurance customer carry an occurred loss himself, or should he make a claim to the insurance company?* This question is important within bonus-malus contracts with individual experience adjustments of the premium. The analysis model includes a bonus hunger strategy where the customers prefer the most profitable financial alternative, that is, the alternative which represents the lowest rate of interest. Hence the loss of bonus after a claim is calculated as a rate of interest paid from the customer to the insurer. Within this model the paper outlines the existence of a true compensation function and a relative cost function for each customer. A set of properties for bonus-malus contracts are presented and discussed. A concrete example of a bonus-malus system and an insurance compensation function illustrates the theoretical framework in a practical manner.

Keywords

Insurance contracts; bonus-malus; bonus hunger; true compensation;
true deductible; relative cost function; optimal loss financing

1. Introduction

Should an insurance customer carry an occurred loss himself, or should he make a claim to the insurance company? This question is quite fundamental under bonus-malus contracts, that is, under insurance contracts with bonus-malus (individual experience rating or no-claim) adjustments, like e.g. motor insurance contracts. It is the general tendency for insurance customers to carry small losses themselves to avoid increases of future premium costs which explains the relevance of the question. This tendency is called the bonus hunger of the insurance customers. The question is more relevant to a customer the harder the loss of bonus rules are, the higher the premium is, and the smaller an occurred loss is, and vice versa. The aim of this paper is to outline and describe how this bonus hunger effect may be taken into account within the framework of optimal loss financing under bonus-malus contracts seen from the customer's point of view.

The question of optimal loss financing is important not only at the time of the loss occurrence, but also when the customers purchase their insurance contracts. If it is rarely worth to let the insurance company carry a loss, why then purchase the contract? This question is in fact part of the general problem of purchasing optimal insurance coverage, which has been extensively studied under varying conditions in insurance economics. Holtan (1999) analyses this problem particularly for bonus-malus contracts. But to do so, we first have to outline the necessary concepts of - and insight to - bonus-malus contracts, which is part of the objective of this paper.

The paper is organized as follows: Section 2 and 3 describe the general insurance contract and the bonus hunger strategy of the customers. Section 4 outlines the general existence of a true compensation function for all insurance contracts with bonus-malus adjustments. Section 5 outlines the existence of relative cost functions for the customer and their general properties. Section 6 and 7 illustrate some of the ideas in section 4 and 5 by doing special assumptions on the bonus-malus system and the insurance compensation function. Section 8 gives some concluding remarks.

2. The general insurance contract

Consider an insurance buyer representing a risk of loss X, where X is a stochastic variable with probability density function $f(x)$ where $x \geq 0$. The insurance contract is characterized by a continuous premium process $p(t)$ transferred from the insured to the insurer at time t, and a compensation $c(x)$ transferred the opposite way if loss $X = x$ obtains. The compensation $c(x)$ is hereby called the *contractual compensation.* Any admissible contractual compensation function satisfies $0 \leq c(x) \leq x$ for all $X = x$. This constraint reflects that there is no compensation if there is no loss ($c(0) = 0$) and that the customer cannot make profit by gambling on his or her risk ($c(x) \not> x$).

3. The bonus hunger strategy

Let the premium process $p(t)$ depend on a bonus-malus system. In principle a bonus-malus system gives the insurance customer a future premium increase if a loss occurrence is compensated by the insurer, and a premium reduction if no loss is compensated. The premium increase is called the loss of bonus, and depends usually only on the number of compensated claims, and not on their amounts. Hence, a customer often makes a profit by self-financing an occurred loss in order to avoid future premium increase, instead of financing the loss by a compensation from the insurer, and thereby accept a future premium increase. This phenomenon is called *bonus hunger.* After a loss occurrence the customer's decision problem is hereby to choose the most profitable financial alternative. Trivial investment theory solves this problem by using *the rate of interest* as the optimal financial criteria, that is, the customer should prefer the financial alternative which represents the lowest rate of interest.

In order to define a bonus hunger strategy (a financial decision rule) for the insurance customer, we use the following notations and assumptions: The premium paid at time t after a loss occurrence at time s is denoted by $p_1(s+t)$ if the loss is reported to the insurer, and by $p_0(s+t)$ if the loss is not reported. Assume $p_0(s+t)$ and $p_1(s+t)$ to be continuos non-stochastic premium processes for all $t > 0$.

Definition 1: Given a loss occurrence at time s with a fixed loss amount $X = x$, the non-stochastic discount rate $\delta(x)$ determined by the net present value equation

$$c(x) = \int_0^{\infty} e^{-\delta t}(p_1(s+t) - p_0(s+t))dt \tag{1}$$

is a *relative measure* of the loss of bonus following that loss. ◊

The discount rate $\delta(x) \in \langle -\infty, \infty \rangle$ is by definition the effective rate of interest for the insurance compensation. To choose the optimal financial alternative after a loss occurrence, the rate of interest for the insurance compensation has to be compared to the effective rate of interest for the financial alternatives, that is, self- financing by savings, by borrowing or by a combination of savings and borrowing, made up by the liquid situation of each customer. Let λ_1 be the borrowing rate and λ_2 be the saving rate (the return rate) at the loss occurrence time s, and assume λ_1 and λ_2 to be positive time-constant parameters. The non-stochastic rate of interest for self-financing, λ, is then defined by (for simplicity disregard taxes):

$$\lambda = \begin{cases} \lambda_1 & \text{if financed by borrowing,} \\ \lambda_2 & \text{if financed by savings,} \\ \beta\lambda_1 + (1-\beta)\lambda_2 & \text{if a share of } \beta \text{ is financed by borrowing and} \\ & \text{a share of } (1-\beta) \text{ is financed by savings.} \end{cases}$$

Hence the bonus hunger strategy for the insurance customer is identified by:

If $\delta > \lambda \Rightarrow$ Self-financing.
If $\delta < \lambda \Rightarrow$ Financing by compensation from the insurer.
If $\delta = \lambda \Rightarrow$ Indifference between the two choices of financing.

4. The true compensation function

A loss of bonus after a claim is obviously paid by the customer, not by the insurer. In principle, this fact identifies the loss of bonus as a deductible paid by the customer to the insurer over a period of time. Hence the *true deductible* of the customer is a combination of the *contractual deductible*, $x - c(x)$, and the loss of bonus. Thus we may define the excess point of the true deductible as that loss amount which makes the insurance customer *indifferent* between the two choices of loss financing, that is, when $\delta = \lambda$. The existence of a true deductible obviously generates a corresponding existence of a *true compensation*, which differs from the earlier defined *contractual compensation* $c(x)$. Exact expressions of the true compensation and the true deductible are defined as follows:

From (1) we define the fixed amount z when $\delta = \lambda$:

$$z = \int_0^\infty e^{-\lambda t}(p_1(s+t) - p_0(s+t))dt . \qquad (2)$$

z is in this context a constant because of the non-stochastic assumptions of λ_1, λ_1, $p_0(s+t)$ and $p_1(s+t)$.

From (1) and (2) we obtain the following modifications of the bonus hunger strategy:

If $\delta > \lambda \Rightarrow c(x) < z \Rightarrow$ Self-financing.
If $\delta < \lambda \Rightarrow c(x) > z \Rightarrow$ Financing by compensation from the insurer.
If $\delta = \lambda \Rightarrow c(x) = z \Rightarrow$ Indifference between the two choices of financing.

Hence, if we assume the customers to follow this optimal bonus hunger strategy, we have:

Definition 2: The true compensation of an occurred loss $X = x$ is defined by:

$$c^*(x) = \begin{cases} c(x) - z & \text{if } c(x) > z \\ 0 & \text{if } c(x) \le z \end{cases} \qquad \Diamond$$

Definition 3: The true deductible of an occurred loss $X = x$ is defined by:

$$d^*(x) = x - c^*(x) = \begin{cases} x - c(x) + z & \text{if } c(x) > z \\ x & \text{if } c(x) \le z \end{cases} \qquad \Diamond$$

$x - c(x) + z$ is the excess point of the true deductible, where $x - c(x)$ is the excess of the contractual deductible and z is the excess of the deductible generated by the loss of bonus. Explicitly we may define:

Definition 4: A bonus-malus contract has a contractual compensation function $c(x)$ and a true compensation function $c^*(x)$. ◊

From (2) we observe that the lower λ is, the higher z is, which by definition 2 gives a lower true compensation $c^*(x)$. Hence we introduce the following proposition:

Proposition 1: A decreasing force of interest in the money market generates a decreasing true compensation, and hence a less favorable insurance profitability for the insurance customers, and vice versa. ◊

Within this framework there exists a lower and an upper limit of $d^*(x)$; both greater than zero. The lower limit is defined when $\lambda \to \infty$, that is, when the relative cost of self-financing goes to infinity, while the upper limit is defined when $\lambda \to 0$, that is, when the relative cost of self-financing goes to zero. Let $z_{\min} = \lim_{\lambda \to \infty} z$ and $z_{max} = \lim_{\lambda \to 0} z$. Hence by definition 3 the lower and upper limit of $d^*(x)$ is defined by:

$$0 < \min\{ x, x\text{-}c(x) + z_{\min} \} \leq d^*(x) \leq \min\{ x, x\text{-}c(x) + z_{max} \} \tag{3}$$

By definition 2 we hereby also define the lower and upper limit of $c^*(x)$:

$$\max\{ 0,\ c(x) - z_{max} \} < c^*(x) < \max\{ 0,\ c(x) - z_{\min} \} \tag{4}$$

Hence by (4) and definition 2 we state two important propositions:

Proposition 2: Independent of the contractual compensation function, the true compensation function has always an individual deductible. ◊

Proposition 3: The compensation function of a bonus-malus contract without a contractual deductible is equivalent to the compensation function of a standard insurance contract with an individual deductible. ◊

Proposition 3 is based on the fact that the true compensation function $max\ (c(x) - z, 0)$ reduces to $max\ (x - z, 0)$ when the bonus-malus contract has no contractual deductible. Since z in this context is the non-stochastic excess value of the deductible generated by the loss of bonus, the compensation function $max\ (x - z, 0)$ has by definition the same form as a standard insurance contract with a deductible z.

Note firstly that even if z is paid over a period of time by increased premiums within a bonus-malus contract, z can nevertheless be considered as a fixed deductible at the time of the loss occurrence. And, not to forget, the customers act as if z is a fixed deductible because they have to make a decision at the time of the loss occurrence. Note secondly that z depends on x via the premium process $p(t)$ and the bonus-malus rules. Hence there exists different compensation functions $max\ (x - z, 0)$ for different customers. This existence does not, however, influence the validation of proposition 3 if we allow *individual* deductibles in standard insurance contracts. In general we have:

Proposition 4: There exists different true compensation functions for different customers. ◊

5. The relative cost function

Definition 1 in section 3 expresses the rate of interest for the insurance compensation on the assumption that the loss amount is already known. If we do not know the size of the loss amount, or more precisely, if the loss amount is a stochastic variable, the rate of interest will also be a stochastic variable. The sample space of this stochastic rate of interest generates something we may call the *relative cost function*. Hence this function is identified by:

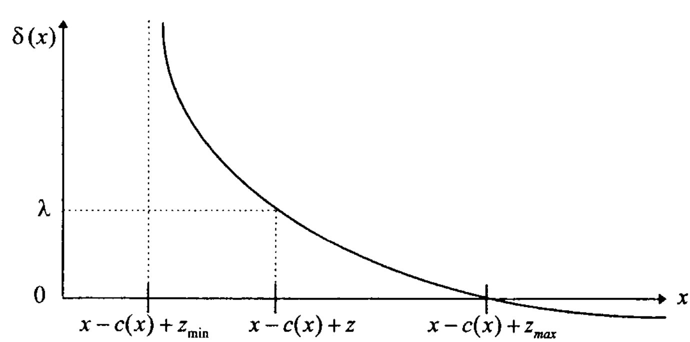
Definition 5: The sample space of the stochastic discount rate $\delta(X) \in \langle -\infty, \infty \rangle$ determined by the net present value function

$$c(X) = \int_0^\infty e^{-\delta t}(p_1(s+t) - p_0(s+t))dt$$

is called the *relative cost function* for all possible loss amounts. ◊

The relative cost function, or *ReCoF* for short, expresses the relationship between all possible loss amounts $x \geq 0$ and their correspondingly rate of interest δ for the insurance compensation. The practical utility of this relationship is obvious: At the beginning of the insurance period the *ReCoF* gives the insurance customers information about their true compensation and their true deductible if a loss occurs during the period. This information is essential within the practical choice of insurance coverage. Figure 1 illustrates the general *ReCoF* and some of the correspondingly vital information.

Figure 1: The general ReCoF - The relative cost function



In figure 1 we observe that the relative cost (the rate of interest δ) for insurance compensation is high for small claims and low for large claims, or more precisely, the *ReCoF* has a decreasing exponential form. The discount component of the present value function in definition 4 makes this characteristic common to all existing bonus-malus systems.

Three essential values are marked out at the horizontal x-axis in figure 1: The left hand value, $x - c(x) + z_{\min}$, is the lower limit of the excess point of the true deductible, while the right hand value, $x - c(x) + z_{max}$, is the upper limit of the excess point of the true deductible. The middle value, x - $c(x)$ + z, that is, when $\delta(x) = \lambda$, is the real excess point of the true deductible for all possible loss amounts $X = x$ given a time-constant rate of interest for self-financing λ. As we e.g. observe, an uncritical reporting of losses with amounts close to $x - c(x) + z_{\min}$ may generate astronomical sized rate of interests for insurance compensation for the customers.

The left hand value and the right hand value at the x-axis generate three essential outcomes of an occurred loss $X = x$:

Outcome 1: $x < x - c(x) + z_{\min} \Leftrightarrow 0 < c(x) < z_{\min}$

Outcome 2: $x - c(x) + z_{\min} < x < x - c(x) + z_{max} \Leftrightarrow z_{\min} < c(x) < z_{max}$

Outcome 3: $x > x - c(x) + z_{max} \Leftrightarrow c(x) > z_{max}$

Common to outcome 1 and 3 are their *independence* of the market parameter λ. In other words, the optimal financial choice of outcome 1 is always self-financing, and the choice is hereby independent of λ. In the same way, the optimal financial choice of outcome 3 is always a financing by insurance compensation. Hence this choice is also independent of λ. Note that if a loss within outcome 1 is less that the excess point of the contractual deductible, then the customer cannot demand any insurance compensation, and hence there exists no financial choice at all.

Outcome 2 is more complex: The financial choice is, unlike outcome 1 and 3, directly *dependent* of the market parameter λ. Within our model, where λ is assumed to be a time-constant parameter, there exists two different outcomes for outcome 2:

Outcome 2a: $x - c(x) + z_{\min} < x < x - c(x) + z \Leftrightarrow z_{\min} < c(x) < z$
Outcome 2b: $x - c(x) + z < x < x - c(x) + z_{max} \Leftrightarrow z < c(x) < z_{max}$

Hence, by the bonus hunger strategy in section 3, outcome 2a generates an optimal self-financing, while outcome 2b generates an optimal financing by insurance compensation. It should be noted that the optimal financial choices within outcome 2 are modified if λ is assumed to be a *stochastic variable*; see section 8 for further discussion/comments on this.

From definition 4 we observe that the *ReCoF* also depends on the individual premium processes $p_0(s+t)$ and $p_1(s+t)$. These processes are again dependent on the individual premium tariff criteria of each customer. Hence we admit the existence of different *ReCoF* for different customers, and hence also the existence of different true deductibles and different true compensations for different customers. We observe e.g. that the higher premium costs a customer pays, the higher is his or her rate of interest for insurance compensation, and hence the higher is his or her true deductible. Given identical losses $X = x$, a customer with high premium costs has to pay a higher rate of interest for insurance compensation than a customer with lower premium costs. Hence, a high risk individual is not only punished once by a high premium, but twice by also a high rate of interest of insurance compensation (which is equivalent to a high true deductible).

According to proposition 4 we conclude this section by the following proposition:

Proposition 5: There exists different relative cost functions for different customers, but all functions are exponential decreasing. ◊

6. Theoretical example

To give further illustrations on the optimal decision problem of the customers, we do the following assumptions of the bonus-malus system and the contractual compensation function:

Bonus-malus system: Let the insurance contract depend on a bonus-malus system which is characterized by a continuos bonus scale where the customer receives a constant premium reduction of percentage (1-k) if no loss is compensated, and a constant premium increase of amount m if a loss is compensated; $0 < k < 1$ and $m > 0$. This system is a modified version of a credibility system with geometric weights described by Sundt (1988), and is chosen because of simple calculating properties. Another modification of this system has been practiced within motor insurance for 10 years (1987-97) by the Norwegian insurance company Storebrand Ltd.; see a detailed description in Neuhaus (1988).

Let us interpret p as the premium paid by the customer at time s, i.e. at the time of the loss occurrence. Hence we have $p_0(s+t) = pk^t$ and $p_1(s+t) = (p+m)k^t$. From (1) we then find:

$$c(x) = \int_0^\infty e^{-\delta t} mk^t dt = \frac{m}{(\delta - \ln k)} \tag{5}$$

$$\Leftrightarrow \quad \delta(x) = \begin{cases} \dfrac{m}{c(x)} + \ln k & \text{if } c(x) > 0 \\ \text{not defined} & \text{if } c(x) = 0 \end{cases} \tag{6}$$

And from (2) we find: $$z = \int_0^\infty e^{-\lambda t} mk^t dt = \frac{m}{(\lambda - \ln k)} \; . \tag{7}$$

The bonus hunger effect within the credibility system with geometric weights has been studied by Sundt (1989). His bonus hunger strategy is close to our strategy, but unlike us, he does not give attention to the optimal financial choice of the customers, i.e. he does not use relative cost as the sufficient bonus hunger criteria.

Contractual compensation: Let the contractual compensation function follow the ordinary excess of loss function identified by:

$$c(x) = \begin{cases} x - d & \text{if } x > d \\ 0 & \text{if } x \leq d \end{cases}$$

where d is a fixed amount called the contractual excess point. Hence the specified bonus-malus system and the contractual compensation function give us specified expressions of $\delta(x)$, $c^*(x)$ and $d^*(x)$ as follows:

$$\delta(x) = \begin{cases} \dfrac{m}{x-d} + \ln k & \text{if } x > 0 \\ \text{not defined} & \text{otherwise} \end{cases} \tag{8}$$

$$c^*(x,k,m,\lambda) = \begin{cases} x - d - \dfrac{m}{\lambda - \ln k} & \text{if } x > d + \dfrac{m}{\lambda - \ln k} \\ 0 & \text{otherwise} \end{cases} \tag{9}$$

$$d^*(x,k,m,\lambda) = \begin{cases} d + \dfrac{m}{\lambda - \ln k} & \text{if } x > d + \dfrac{m}{\lambda - \ln k} \\ x & \text{otherwise,} \end{cases} \tag{10}$$

where $d + m/(\lambda - \ln k)$ is called the true excess point.

It should be noted that the expressions (8) - (10) contain an underlying assumption of a fixed dependency between the contractual excess point d and the premiums $p_0(s+t)$ and $p_1(s+t)$. In other words; in (8) - (10) d can not be interpreted as a varying parameter. See section 7 for a wider discussion on this.

From (3) and (10) we find the lower and upper limit of $d^*(x)$:

$$z_{\min} = \lim_{\lambda \to \infty} \frac{m}{(\lambda - \ln k)} = 0 \qquad z_{max} = \lim_{\lambda \to 0} \frac{m}{(\lambda - \ln k)} = \frac{m}{-\ln k}.$$

Hence we have:

$$0 < \min(m,d) \leq d^*(x) \leq \min(x, d - m/\ln k)\,. \qquad (11)$$

And from (4) and (9) we also find the lower and upper limit of $c^*(x)$:

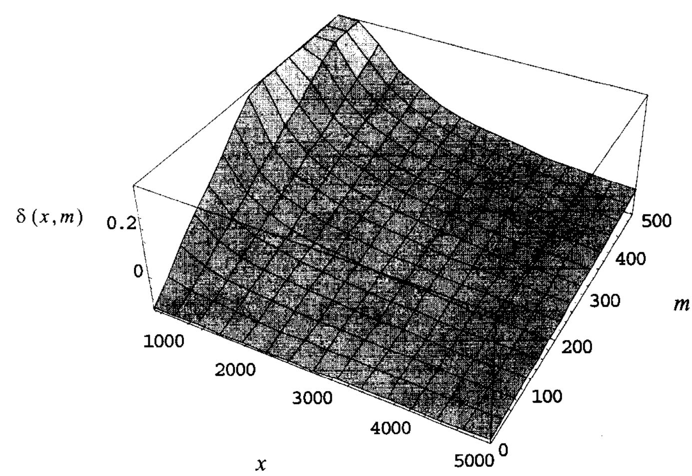
$$max(0, x - d + m/\ln k) < c^*(x) < max(0, x - d) \qquad (12)$$

7. Numerical studies

There are several ways to study the expressions (8) - (10) numerically. Here we present two of them:

Study 1:
Let $k = 0.87$ (like the old system in Storebrand) and let $d = 0$. Hence figure 2 shows a three dimensional picture of the values of $\delta(x,m)$ where \$ 500 $\leq x \leq$ \$ 5000 and $0 \leq m \leq$ \$ 500.

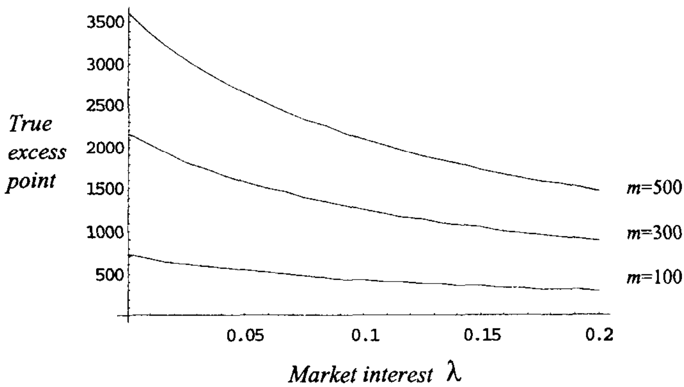
Figure 2



As earlier indicated, we observe that small loss amounts x give very high rate of interest δ for the insurance compensation, and vice versa. A higher premium increase m after a loss compensation gives also a higher δ, but not so high as small loss amounts. As pointed out in figure 1 and in proposition 5, we also observe the general exponential decreasing form of $\delta(x)$. In figure 2 the lower limit of the excess point of the true deductible, $x - c(x) + z_{\min}$, is zero (by straightforward calculation), while the upper limit of the excess point of the true deductible, $x - c(x) + z_{max}$, is $m/(-\ln k) = m/0.139$.

Study 2:
Like study 1 let $k = 0.87$ and $d = 0$. Let m take three different values: m = \$ 100, m = \$ 300 and m = \$ 500. Hence figure 3 shows a two dimensional figure of the true excess point $d + m/(\lambda - \ln k)$ as a function of the market interest λ (where $0 \le \lambda \le 20\%$) for the three values of m.

Figure 3



In figure 3 we observe - as earlier pointed out generally in proposition 1 - that the higher the market interest λ is, the lower is the true excess point, and hence the more favorable the insurance contract is for the insurance customers. Or in other words; an increasing force of interest in the money market generates a lower true excess point and more reported claims to the insurance company, and vice versa. And as we observe, this effect is stronger the harder the premium increase m is after a claim.

Premium vs. the contractual excess point
Recall the underlying assumption of a fixed dependency between the contractual excess point d and the premiums $p_0(s+t)$ and $p_1(s+t)$ in the expressions (8) - (10) in section 6. In a real world the premium size is obviously influenced by the size of d. Hence, if we want to interpret d as a varying parameter, we have to make concrete assumptions about the dependency between the premium and the customer's choice of d. One very simple method is to let the premium = $p(d) = \omega p$ where $\omega = \exp(-\beta d)$. ω is here interpreted as the per cent discount of the deductible d: $p(0) = p$ and $p(\infty) = 0$. The parameter β has to be determined such that ω generates reasonable values.

The above premium modifications give $p_0(s+t) = \exp(-\beta d)pk^t$ and $p_1(s+t) = \exp(-\beta d)(p+m)k^t$. Hence formula (5) in section 6 is e.g. corrected to $c(x) = m\exp(-\beta d)/(\delta - \ln k)$, which again leads to similarly corrections in the expressions (6) - (12).

8. Concluding remarks

The outline of optimal loss financing under bonus-malus contracts is based on a set of assumptions of the purchasing behavior of the customers. Two assumptions may generate some discussion: 1) The loss of bonus z after a loss occurrence will always be paid by the customer, and 2) the customer will always choose the most profitable financial alternative after a loss occurrence.

An objection to the first assumption may be that the loss of bonus z becomes zero if the customer breaks the insurance contract the year after the claim. This situation is, however, taken care of by definition (2) of z in section 4. Definition (2) gives in this case $z = 0$ since both $p_1(s+t) = 0$ and $p_0(s+t) = 0$ after the contract break. Hence, the value of z is based on the individual (behavior of the) customer, as earlier pointed out in section 4. If the time horizon of the customer is to break the contract the year after a loss, then z becomes zero and the bonus-malus contract becomes a one period standard contract without malus adjustments.

An objection to the second assumption may be that the customers may choose insurance compensation even if it is more optimal to carry occurred losses themselves. Hence $c^*(x)$ in definition 2 in section 4 becomes negative. This will typically happen if the customer is forced to choose insurance compensation because of his or her bad financial position. This situation may be eliminated if the insurer offers a financial service program as a supplement to the bonus-malus insurance contract, and hence takes care of the financial needs of the insurance customer. These needs are probably underestimated by insurance companies as well as by banks. Holtan (1995) gives some ideas of financial services based on these needs. Anyway, because the aim of this paper is to find optimal loss financing properties under bonus-malus contracts, the second assumption seems after all to be a reasonable assumption.

The question of optimal loss financing is directly linked to insurance purchasing questions like: If it is rarely worth to let the insurance company carry a loss, why then purchase the contract? Or in other words: Should - or should not - an individual customer buy a bonus-malus insurance contract? And if so, what insurance coverage should he or she prefer? These questions lead to a classical field of insurance economics: optimal insurance coverage. Holtan (1999), which is based on - and a direct extension of - this paper, analyses these questions particularly for bonus-malus contracts.

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