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ASTIN Bulletin

47(1), 2017

TAYLOR, GREG. *Existence and uniqueness of chain ladder solutions*. 1–41. The cross-classified chain ladder has a number of versions, depending on the distribution to which observations are subject. The simplest case is that of Poisson distributed observations, and then maximum likelihood estimates of parameters are explicit. Most other cases, however, including Bayesian chain ladder models, lead to implicit MAP (Bayesian) or MLE (non-Bayesian) solutions for these parameter estimates, raising questions as to their existence and uniqueness. The present paper investigates these questions in the case where observations are distributed according to some member of the exponential dispersion family.

BLACKBURN, CRAIG; HANEWALD, KATJA; OLIVIERI, ANNAMARIA; SHERRIS, MICHAEL. *Longevity risk management and shareholder value for a life annuity business*. 43–77. The life annuity business is heavily exposed to longevity risk. Risk transfer solutions are not yet fully developed, and when available they are expensive. A significant part of the risk must therefore be retained by the life insurer. So far, most of the research work on longevity risk has been mainly concerned with capital requirements and specific risk transfer solutions. However, the impact of longevity risk on shareholder value also deserves attention. While it is commonly accepted that a market-consistent valuation should be performed in this respect, the definition of a fair shareholder value for a life insurance business is not trivial. In this paper, we develop a multi-period market-consistent shareholder value model for a life annuity business. The model allows for systematic and idiosyncratic longevity risk and includes the most significant variables affecting shareholder value: the cost of capital (which in a market-consistent setting must be quantified in terms of frictional and agency costs, net of the value of the limited liability put option), policyholder demand elasticity and the cost of alternative longevity risk management solutions, namely indemnity-based and index-based solutions. We show how the model can be used for assessing the impact of different longevity risk management strategies on life insurer shareholder value and solvency.

LIU, YANXIN; SIU-HANG, LI JOHNNY. *The locally linear Cairns–Blake–Dowd model: a note on delta–nuga hedging of longevity risk*. 79–151. Although longevity risk arises from both the variation surrounding the trend in future mortality and the uncertainty about the trend itself, the latter is often left unmodeled. In this paper, we address this problem by introducing the locally linear CBD model, in which the drifts that govern the expected mortality trend are allowed to follow

a stochastic process. This specification results in median forecasts that are more consistent with the recent trends and more robust relative to changes in the data sample period. It also yields wider prediction intervals that may better reflect the possibilities of future trend changes. The treatment of the drifts as a stochastic process naturally calls for nuga hedging, a method proposed by Cairns (2013) to hedge the risk associated with changes in drifts. To improve the existing nuga-hedging method, we propose a new hedging method which demands less stringent assumptions. The proposed method allows hedgers to extract more hedge effectiveness out of a hedging instrument, and is therefore useful when there are only a few traded longevity securities in the market.

HUANG, SHUJUAN; HARTMAN, BRIAN; BRAZAUSKAS, VYTARAS. *Model selection and averaging of health costs in episode treatment groups.* 153–167. Episode Treatment Groups (ETGs) classify related services into medically relevant and distinct units describing an episode of care. Proper model selection for those ETG-based costs is essential to adequately price and manage health insurance risks. The optimal claim cost model (or model probabilities) can vary depending on the disease. We compare four potential models (lognormal, gamma, log-skew-*t* and Lomax) using four different model selection methods (AIC and BIC weights, Random Forest feature classification and Bayesian model averaging) on 320 ETGs. Using the data from a major health insurer, which consists of more than 33 million observations from 9 million claimants, we compare the various methods on both speed and precision, and also examine the wide range of selected models for the different ETGs. Several case studies are provided for illustration. It is found that Random Forest feature selection is computationally efficient and sufficiently accurate, hence being preferred in this large data set. When feasible (on smaller data sets), Bayesian model averaging is preferred because of the posterior model probabilities.

ZHANG, ZHIMIN. *Approximating the density of the time to ruin via fourier-cosine series expansion.* 169–198. In this paper, the density of the time to ruin is studied in the context of the classical compound Poisson risk model. Both one-dimensional and two-dimensional Fourier-cosine series expansions are used to approximate the density of the time to ruin, and the approximation errors are also obtained. Some numerical examples are also presented to show that the proposed method is very efficient.

PÉREZ, JOSÉ-LUIS; YAMAZAKI, KAZUTOSHI. *Refraction–reflection strategies in the dual model.* 199–238. We study the dual model with capital injection under the additional condition that the dividend strategy is absolutely continuous. We consider a *refraction–reflection strategy* that pays dividends at the maximal rate whenever the surplus is above a certain threshold, while capital is injected so that it stays non-negative. The resulting controlled surplus process becomes the spectrally positive version of the refracted–reflected process recently studied by Pérez and Yamazaki (2015). We study various fluctuation identities of this process and prove the optimality of the refraction–reflection strategy. Numerical results on the optimal dividend problem are also given.

ZHU, JINXIA. *Optimal financing and dividend distribution with transaction costs in the case of restricted dividend rates.* 239–268. We consider the optimal financing (capital injections) and dividend payment problem for a Brownian motion model in the case of restricted dividend rates. The company has no obligation to inject capitals and therefore, the bankruptcy risk is present. Capital injections, if any, will incur both fixed and proportional transaction costs and dividend payments incur proportional transaction costs. The aim is to find the optimal strategy to

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maximize the expected present value of dividend payments minus the total cost of capital injections up to the time of bankruptcy. The problem is formulated as a mixed impulse-regular control problem. We address the problem via studying three cases of two auxiliary functions. We derive important analytical properties of the auxiliary functions and use them to study the value function and then identify the optimal control strategy. We show that the optimal dividend control is of threshold type and the optimal financing strategy prescribes to either never inject capitals or inject capitals only when the surplus reaches 0 with a fixed lump sum amount.

WU, RENCHAO; PANTELOUS, ATHANASIOS A. *Potential games with aggregation in non-cooperative general insurance markets*. 269–302. In the global insurance market, the number of product-specific policies from different companies has increased significantly, and strong market competition has boosted the demand for a competitive premium. Thus, in the present paper, by considering the competition between each pair of insurers, an N-player game is formulated to investigate the optimal pricing strategy by calculating the Nash equilibrium in an insurance market. Under that framework, each insurer is assumed to maximise its utility of wealth over the unit time interval. With the purpose of solving a game of N-players, the best-response potential game with non-linear aggregation is implemented. The existence of a Nash equilibrium is proved by finding a potential function of all insurers' payoff functions. A 12-player insurance game illustrates the theoretical findings under the framework in which the best-response selection premium strategies always provide the global maximum value of the corresponding payoff function.

BOONEN, TIM J. *Risk redistribution games with dual utilities*. 303–329. This paper studies optimal risk redistribution between firms, such as institutional investors, banks or insurance companies. We consider the case where every firm uses dual utility (also called a distortion risk measure) to evaluate risk. We characterize optimal risk redistributions via four properties that need to be satisfied jointly. The characterized risk redistribution is unique under three conditions. Whereas we characterize risk redistributions by means of properties, we can also use some results to study competitive equilibria. We characterize uniqueness of the competitive equilibrium in markets with dual utilities. Finally, we identify two conditions that are jointly necessary and sufficient for the case that there exists a trade that is welfare-improving for all firms.

SU, JIANXI; FURMAN, EDWARD. *A form of multivariate pareto distribution with applications to financial risk measurement*. 331–357. A new multivariate distribution possessing arbitrarily parametrized and positively dependent univariate Pareto margins is introduced. Unlike the probability law of Asimit *et al.* (2010), the structure in this paper is absolutely continuous with respect to the corresponding Lebesgue measure. The distribution is of importance to actuaries through its connections to the popular frailty models, as well as because of the capacity to describe dependent heavy-tailed risks. The genesis of the new distribution is linked to a number of existing probability models, and useful characteristic results are proved. Expressions for, e.g., the decumulative distribution and probability density functions, (joint) moments and regressions are developed. The distributions of minima and maxima, as well as, some weighted risk measures are employed to exemplify possible applications of the distribution in insurance.

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Geneva Risk and Insurance Review

42(1), 2017

SALANIÉ, BERNARD. *Equilibrium in insurance markets: an empiricist's view*. 1–14. Empirical
models of insurance markets would greatly enhance our ability to understand policy-relevant
questions. Yet they are still quite rare. This paper sketches such a model and surveys its basic
elements. While much progress has been made in recent years in our understanding of insurance
demand in particular, the most crying need is for market-wide data.

POSEY, LISA L; BAJTELSMIT, VICKIE. *Insurance and endogenous bankruptcy risk: when is it
rational to choose gambling, insurance, and potential bankruptcy?* 15–40. We examine the
coexistence of insurance and gambling in the context of limited liability. We develop a model
where actuarially fair insurance is available to a risk-averse decision maker for a liability risk with
non-bankrupting severity. The remaining wealth may be invested in a zero expected value risky
project (i.e., gambled). The risk of bankruptcy is endogenous since either fully insuring or for-
going the project will guarantee solvency. We show that, for a range of parameters, it is optimal
to both insure and gamble. The amounts insured and invested are chosen to create the potential
for bankruptcy. Our results are robust to the cases where the risky project can cause bankruptcy
without a liability loss and where the risky project's expected return is nonzero.

HAJIMOLADARVISH, NARGES. *Very low probabilities in the loss domain*. 41–58. This experi-
mental study uses a non-parametric method to investigate probability weighting functions for
very low probabilities in the loss domain. Probability weights in three loss situations containing
small, large and heterogeneous losses composed of both small and large losses are elicited. While
most of the probabilities under consideration are significantly overweighted, the probability
weighting function exhibits the much replicated inverse S-shaped functions when losses are small.
Interestingly, the more common probabilities, 0.1 and 0.01, get underweighted by more than half
of the sample in small and heterogeneous loss situations, respectively. Probability underweighting
is accompanied by risk-loving behaviour that can have implications for design of contracts and
policies designed to control risky behaviours.

FERRANNA, MADDALENA. *Does inefficient risk sharing increase public self-protection?* 59–85.
This paper studies how the risk of having an unequal distribution of income across the population
affects the investment in a public self-protection policy, such as financial regulation or climate
change mitigation. Two economies are compared. In the first economy, there is perfect risk
sharing, i.e., individuals can credibly commit on a set of transfers that will remove ex-post
inequalities in consumption. In the second economy, no risk sharing takes place. By referring to
the literature on background risks, I determine some conditions in terms of change in risk
aversion and prudence, which guarantee an increase in self-protection under inefficient risk

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sharing. Generally speaking, if self-protection reduces the risk of inequality, the investment tends to rise when either the probability of a catastrophic event and/or the risk of inequality are sufficiently low. If self-protection increases the risk of inequality, the investment tends to rise when both the probabilities of aggregate loss and the increase in the risk of inequality are sufficiently small.

North American Actuarial Journal

21(1), 2017

CHI, YICHUN; ZHOU, MING. *Optimal reinsurance design: a mean-variance approach*. 1–14. In this article, we study an optimal reinsurance model from the perspective of an insurer who has a general mean-variance preference. In order to reduce ex post moral hazard, we assume that both parties in a reinsurance contract are obligated to pay more for a larger realization of loss. We further assume that the reinsurance premium is calculated only based on the mean and variance of the indemnity. This class of premium principles is quite general in the sense that it includes many widely used premium principles such as expected value, mean value, variance, and standard deviation principles. Moreover, to protect the insurer's profit, a lower bound is imposed on its expected return. We show that any admissible reinsurance policy is dominated by a change-loss reinsurance or a dual change-loss reinsurance, depending upon the coefficient of variation of the ceded loss. Further, the change-loss reinsurance is shown to be optimal if the premium loading increases in the actuarial value of the coverage; while it becomes decreasing, the optimal reinsurance policy is in the form of dual change loss. As a result, the quota-share reinsurance is always optimal for any variance-related reinsurance premium principle. Finally, some numerical examples are applied to illustrate the applicability of the theoretical results.

GHOSSOUB, MARIO. *Arrow's theorem of the deductible with heterogeneous beliefs*. 15–35. In Arrow's classical problem of demand for insurance indemnity schedules, it is well-known that the optimal insurance indemnification for an insurance buyer—or decision maker (DM)—is a *deductible* contract when the insurer is a risk-neutral Expected-Utility (EU) maximizer and when the DM is a risk-averse EU maximizer. In Arrow's framework, however, both parties share the same probabilistic beliefs about the realizations of the underlying insurable loss. This article reexamines Arrow's problem in a setting where the DM and the insurer have different subjective beliefs. Under a requirement of compatibility between the insurer's and the DM's subjective beliefs, we show the existence and monotonicity of optimal indemnity schedules for the DM. The belief compatibility condition is shown to be a weakening of the assumption of a monotone likelihood ratio. In the latter case, we show that the optimal indemnity schedule is a variable deductible schedule, with a state-contingent deductible that depends on the state of the world only through the likelihood ratio. Arrow's classical result is then obtained as a special case.

BELKINA, TATIANA; LUO, SHANGZHEN. *Asymptotic investment behaviors under a jump-diffusion risk process*. 36–62. We study an optimal investment control problem for an insurance

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company. The surplus process follows the Cramer-Lundberg process with perturbation of a Brownian motion. The company can invest its surplus into a risk-free asset and a Black-Scholes risky asset. The optimization objective is to minimize the probability of ruin. We show by new operators that the minimal ruin probability function is a classical solution to the corresponding HJB equation. Asymptotic behaviors of the optimal investment control policy and the minimal ruin probability function are studied for low surplus levels with a general claim size distribution. Some new asymptotic results for large surplus levels in the case with exponential claim distributions are obtained. We consider two cases of investment control: unconstrained investment and investment with a limited amount.

BERNARD, CAROLE; CUI, ZHENYU; VANDUFFEL, STEVEN. *Impact of flexible periodic premiums on variable annuity guarantees*. 63–86. In this article, we study the fair fee of a flexible premium variable annuity (FPVA), in which the policyholder can choose to pay periodic premiums during the accumulation phase instead of a single initial premium. We are able to express fair fees using a fast and accurate approximation based on bounds on the price of the FPVA. We identify scenarios that are particularly costly for the insurer. Our study could help insurers estimate the magnitude of typical underpricing when offering flexible-premium variable annuities with the same fee as the corresponding single-premium variable annuity.

ZHANG, YAN; WU, YONGHONG; LI, SHUANG; WIWATANAPATAPHEE, BENCHAWAN. *Mean-variance asset liability management with state-dependent risk aversion*. 87–106. This article investigates the asset liability management problem with state-dependent risk aversion under the mean-variance criterion. The investor allocates the wealth among multiple assets including a risk-free asset and multiple risky assets governed by a system of geometric Brownian motion stochastic differential equations, and the investor faces the risk of paying uncontrollable random liabilities. The state-dependent risk aversion is taken into account in our model, linking the risk aversion to the current wealth held by the investor. An extended Hamilton-Jacobi-Bellman system is established for the optimization of asset liability management, and by solving the extended Hamilton-Jacobi-Bellman system, the analytical closed-form expressions for the time-inconsistent optimal investment strategies and the optimal value function are derived. Finally, numerical examples are presented to illustrate our results.

O'HAGAN, ADRIAN; FERRARI, COLM. *Model-based and nonparametric approaches to clustering for data compression in actuarial applications*. 107–146. Clustering is used by actuaries in a data compression process to make massive or nested stochastic simulations practical to run. A large data set of assets or liabilities is partitioned into a user-defined number of clusters, each of which is compressed to a single representative policy. The representative policies can then simulate the behavior of the entire portfolio over a large range of stochastic scenarios. Such processes are becoming increasingly important in understanding product behavior and assessing reserving requirements in a big-data environment. This article proposes a variety of clustering techniques that can be used for this purpose. Initialization methods for performing clustering compression are also compared, including principal components, factor analysis, and segmentation. A variety of methods for choosing a cluster's representative policy is considered. A real data set comprising variable annuity policies, provided by Milliman, is used to test the proposed methods. It is found that the compressed data sets produced by the new methods, namely, model-based clustering, Ward's minimum variance hierarchical clustering, and k-medoids clustering, can replicate the behavior of the uncompressed (seriatim) data more accurately than those obtained by the existing Milliman method. This is verified within sample by examining location variable totals of the representative

policies versus the uncompressed data at the five levels of compression of interest. More crucially it is also verified out of sample by comparing the distributions of the present values of several variables after 20 years across 1000 simulated scenarios based on the compressed and seriatim data, using Kolmogorov-Smirnov goodness-of-fit tests and weighted sums of squared differences.

HUA, LEI; XIA, MICHELLE; BASU, SANJIB. *Factor copula approaches for assessing spatially dependent high-dimensional risks*. 147–160. In this article, we propose an innovative approach for modeling spatial dependence among losses from various geographical locations. The proposed model converts the challenging task of modeling complex spatial dependence structures into a relatively easier task of estimating a continuous function, of which the arguments can be the coordinates of the locations. The approach is based on factor copula models, which can capture various linear and nonlinear dependence. We use radial basis functions as the kernel smoother for estimating the key function that models all the spatial dependence structures. A case study on a thunderstorm wind loss dataset demonstrates the analysis and the usefulness of the proposed approach. Extensions to spatiotemporal models and to models for discrete data are briefly introduced, with an example given for modeling loss frequency with excess zeros.

CHEUNG, KA CHUN; LO, AMBROSE. *Characterizations of optimal reinsurance treaties: a cost-benefit approach*. 1–28. This article investigates optimal reinsurance treaties minimizing an insurer's risk-adjusted liability, which encompasses a risk margin quantified by distortion risk measures. Via the introduction of a transparent cost-benefit argument, we extend the results in Cui et al. [Cui, W., Yang, J. & Wu, L. (2013). Optimal reinsurance minimizing the distortion risk measure under general reinsurance premium principles. *Insurance: Mathematics and Economics* 53, 74–85] and provide full characterizations on the set of optimal reinsurance treaties within the class of non-decreasing, 1-Lipschitz functions. Unlike conventional studies, our results address the issue of (non-)uniqueness of optimal solutions and indicate that ceded loss functions beyond the traditional insurance layers can be optimal in some cases. The usefulness of our novel cost-benefit approach is further demonstrated by readily solving the dual problem of minimizing the reinsurance premium while maintaining the risk-adjusted liability below a fixed tolerance level.

ADÉKAMBI, FRANCK; CHRISTIANSEN, MARCUS C. *Integral and differential equations for the moments of multistate models in health insurance*. 29–50. The moments of the random future liabilities of health insurance policies are key quantities for studying distributional properties of the future liabilities. Assuming that the randomness of the future health status of individual policyholders can be described by a semi-Markovian multistate model, integral and differential equations are derived for moments of any order and for the moment generating function. Different representations are derived and discussed with a view to numerical solution methods.

ZHANG, ZHIMIN; CHEUNG, ERIC C.K.; YANG, HAILIANG. *Lévy insurance risk process with Poissonian taxation*. 51–87. The idea of taxation in risk process was first introduced by Albrecher, H. & Hipp, C. Lundberg's risk process with tax. *Blätter der DGVFM* 28(1), 13–28, who suggested that a certain proportion of the insurer's income is paid immediately as tax whenever the surplus process is at its running maximum. In this paper, a spectrally negative Lévy insurance risk model under taxation is studied. Motivated by the concept of randomized observations proposed by Albrecher, H., Cheung, E.C.K. & Thonhauser, S. Randomized observation periods for the compound Poisson risk model: Dividends. *ASTIN Bulletin* 41(2), 645–672, we assume that the insurer's surplus level is only observed at a sequence of Poisson arrival times, at which the event of ruin is checked and tax may be collected from the tax authority. In particular, if the observed (pre-tax) level exceeds the maximum of the previously observed (post-tax) values, then a fraction of the excess will be paid as tax. Analytic expressions for the Gerber–Shiu expected discounted penalty function and the expected discounted tax payments until ruin are derived. The Cramér-Lundberg asymptotic formula is shown to hold true for the Gerber–Shiu function, and it differs from the case without tax by a multiplicative constant. Delayed start of tax payments will be discussed as well. We also take a look at the case where solvency is monitored continuously (while tax is still paid at Poissonian time points), as many of the above results can be derived in a similar manner. Some numerical examples will be given at the end.

CHEUNG, KA CHUN; DENUIT, MICHEL; DHAENE, JAN. *Tail mutual exclusivity and Tail-VaR lower bounds*. 88–104. In this paper, we extend the concept of mutual exclusivity proposed by [Dhaene, J. & Denuit, M. (1999). The safest dependence structure among risks. *Insurance: Mathematics and Economics* 25, 11–21] to its tail counterpart and baptize this new dependency structure as tail mutual exclusivity. Probability levels are first specified for each component of the random vector. Under this dependence structure, at most one exceedance over the corresponding Value-at-Risks (VaRs) is possible, the other components being zero in such a case. No condition is imposed when all components stay below the VaRs. Several properties of this new negative dependence concept are derived. We show that this dependence structure gives rise to the smallest value of Tail-VaR (TVaR) of a sum of risks within a given Fréchet space, provided that the probability level of the TVaR is close enough to one.

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