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Risk Measures, Measures for Insolvency Risk and Economical Capital Allocation

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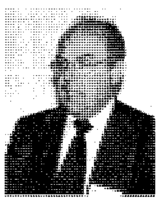

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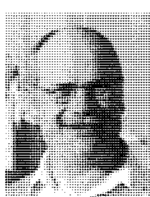

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ABSTRACT

In the present paper we consider several measures for the risk that is present in an insurance environment. We look for desirable properties for two types of risk measures, the ones reflecting both negative and positive results, and the measures for insolvency risks dealing with aspects of ruin, as well as their relation to the allocation of economic capital to different business lines or to the different subcompanies constituting a financial conglomerate. The main problem for both types of measurements is that the dependence structure that exists between the different units involved is unknown.

I. INTRODUCTION

Both an insurance premium and the price of a financial product can be regarded as a measure of the risk involved in the financial transaction between the buyer of the product and the seller in the market. The insurance premium or the price as a risk measure is expressed in the right units, having the dimension of the transaction (money). In the actuarial literature, insurance premium principles have been studied extensively, see e.g. Bühlmann (1970), Gerber (1979) and Goovaerts *et al.* (1984). The pricing of financial risks is a key topic in finance, see e.g. Gerber and Shiu (1994). In section III, a link between actuarial pricing (by a premium principle) and financial pricing (by means of expectation) is given. It is argued that in general for risks, the corresponding insurance premium principle (and hence also the risk measure) cannot be assumed to be additive, subadditive or superadditive in all situations. Indeed, a situation in which superadditivity is preferable is when a risk $2x$ is to be insured. For any risk averse insurer, the premium for $2x$, and hence the 'risk' associated with this random variable, will be strictly more than twice the one for x. For an economic principle, it seems better to require subadditivity for independent risks (more is better and safer because of the law of large numbers, and because of possible hedging), but this is not the case for *dependent* risks which are a common phenomenon in an insurance context. The two situations, dependent risks on the one hand and independent risks on the other, should be approached in quite different ways.

II. DISCUSSION OF DESIRABLE PROPERTIES

In what follows, we will develop arguments indicating that imposing general axioms valid for all risky situations conflicts with generally accepted properties for dealing with particular sets of risks, based on what could be called as 'best practice' rules. We will show that pure risk measures should possess other properties than measures developed for solvency purposes.

Some examples are examined to support this assertion.

Example 1

In earthquake risk insurance, it is better (hence a lower price results) to insure two independent risks than two positively dependent risks *(two buildings in the same area). For insuring a risk fully, the premium should be more than twice the premium for insuring only half of the risk. The exchange of portions of life portfolios between different continents is an example illustrating the importance of a geographical spread of risks (in order to make them more independent). As a consequence, we see that imposing subadditivity for all risks (including dependent risks) is not in line with what could be called 'best practice'. In Section III we will indicate the danger of imposing properties to all risks in a given set.*

In the framework of risk measures, it is also clear that percentiles or related measures do not catch the risky character of a risk in an economically sensible way. This simply means that when the Value At Risk (VAR) is used to measure risk, it makes for instance no sense to consider subadditivity. This notion arises from the contamination with the problem of supervision, where the supervisor or a rating agency wants to end up with an upper bound for the integrated risk of the sum of several portfolios. In that situation it would be nice to have a measure for insolvency risk that can be obtained by adding the measures for each of the portfolios, or merely an upper bound for it. Section V will give one possible answer.

Example 2

Consider a combined risk (payments) distributed uniformly on 0,0.9 with probability mass 0.9 and uniformly distributed in 0.9,1 with probability mass 0.1. The risk is uniform(0,1), and the 0.1 percentile equals 0.9. According to the percentile criterion at the level 0.1, this random variable is as dangerous as the one with mass 0.9 in 0,0.9 uniformly distributed but combined with an additional mass in 1000,1000.05 uniformly distributed with total mass 0.05 and an additional mass (also uniformly distributed) in 0.9,1 with total mass 0.05.

So a tail characteristic like the VAR on its own is not a good risk measure and is not in line with best practice rules. By using the VAR as a criterion, one implicitly assumes that the distributions that are compared are of a similar type, for instance a normal distribution.

It should be remarked that the conditional expectation, e.g. above the 0.9 percentile, does make a distinction between the two situations in Example 2. Example 1 indicates that serious problems may arise from assuming subadditivity.

Clearly, subadditivity is not desirable in case dependence aspects of the risks are important. Premium principles satisfying the properties of (sub-)additivity were restricted to independent risks. Risk measures should cope with dependencies as well as with tails.

A problem not to be confused with the problem of defining a risk measure for a set of risks consists in the determination of a measure for insolvency risk. This problem originates from a very practical situation where within a financial conglomerate one wants one figure to summarize the risks of a set of different (possibly) dependent subcompanies. The same problem arises in case we consider one financial and/or insurance institution with different portfolios or business lines. Here the final aim is related but different from the aim of determining a risk measure. For each of the separate subcompanies (dependent or not) one can derive a measure for the insolvency risk based on the relevant statistical material that comes from within the subcompany (hence only marginal statistical data are used). Here the question arises whether the sum of the measures of insolvency for the individual subcompanies gives an *upper* bound of the risk measure for the sum of risks contained in the financial conglomerate. This may resemble the concept of subadditivity but in reality it is not the same. It is a problem of finding the best upper bound for the measure of insolvency of the sum of risks for which we know a measure of insolvency for each of the individual companies (marginally). This is directly related to the following question: if a financial conglomerate has a risk based capital available that amounts to d, then how can one distribute this amount in $d_1 + d_2 + \ldots + d_n = d$ between the subcompanies in such a way that the total measure of insolvency is known, only based on the measures of insolvency risk of each of the separate companies. This question will be dealt with in Section IV.

We consider another example indicating the danger of imposing a general property for measures of insolvency risk:

Example 3

Consider a uniform risk X in the interval $[9,10]$ and compare it with a risk Y that is a certainty risk of 1000. Clearly $Pr[X<Y]=1$ but in $X-E[X]$ there might be a risk of insolvency, while $Y-E[Y]$ presents no risk at all.

Hence, a risk measure should incorporate a component reflecting the mean of the risk.

III. INSURANCE PREMIUMS VERSUS PRICING IN FINANCE

In Goovaerts *et al.* (1984) it is shown how the Esscher transform emerges from the utility theory in measuring the price of a random variable. Indeed, one has the following theorem:

Theorem 1

Assume an insurer has an exponential utility function with risk aversion α. If he charges a premium of the form $E[\varphi(X)X]$ where $\varphi(.)$ is a continuous increasing function with $E[\varphi(X)] = 1$, his utility is maximized if $\varphi(x)$ α $e^{\alpha x}$, i.e. if he uses the Esscher premium principle with parameter ά.

For a proof of this theorem, we refer to Goovaerts *et al.* (1984). If the utility function u is exponential, e.g. $u(x) = 1 - e^{-hx}$, then

$$\varphi(x) = \frac{e^{hx}}{M(h)},$$

which leads to the Esscher transform of the risk X. If $u(x)$ is quadratic, hence e.g. $u(x) = ax^2 + bx$, using the same arguments we get $\varphi(x)$ α $2ax + b$, and $E[\varphi(X)] = 1$ gives

$$E[X\varphi(X)] = E[X(2aX + b)/E[2aX + b]] = \frac{2aE[X^2] + bE[X]}{2aE[X] + b}$$

$$= E[X] + \frac{1}{E[X] + b/2a}\operatorname{var}[X]$$

which is a variance premium principle where the variance loading parameter depends on the mean risk. This is no restriction if only risks with a given expectation are considered.

It has been argued that the variance premium principle is pointless because it might be that a larger risk (with probability 1) requires a lower premium, (see Kaas *et al.* (2001), Example 10.4.5). But for risks with the same expectation, the variance is a reliable risk measure. In the sequel, we will often consider normalized risks $X-E[X]$. In that case it immediately follows that, taking into account the dependence structure one gets the three types of additivity as it should be. See also the draft report of the solvency working party of the IAA, October 2001.

We would like to note that if one uses the variance as a measure of insolvency, which according to utility theory is an adequate measure, adding risk measures and imposing risk properties such as subadditivity does not make any sense. Indeed if $X_1, \ldots, X_n$ are identically distributed with zero mean and non-degenerate, of which $X_1^c, \ldots, X_n^c$ are the comonotonic versions (having the same marginal cdf's, but maximal dependence), then

$$Var[X_1^c + \ldots + X_n^c] = n^2 Var[X_1] > n Var[X_1] = \sum Var[X_i].$$

This indicates that for comonotonic risks, superadditivity seems to be desirable. As we will explain, addition of insolvency measures makes only sense in relation to the distribution of economic capital. In addition additivity is useful in case of the repartition on the down level of a premium income, determined on the top level.

In discussions concerning the subadditivity of risks measures the arguments used are often far from realistic. Indeed it is said that additivity is the worst that can be obtained in case of standard deviation $\sigma[X_1 + X_2] \leq \sigma[X_1] + \sigma[X_2]$ (equality holds only in case of a correlation +1). This is the argument used for subadditivity, even though the standard deviation premium must be ruled out as a risk measure because even though X is smaller than Y with probability 1, it might happen that its standard deviation premium is larger. The standard deviation principle should indeed be used as a risk measure only for random variables with unequal expectations. It is important to note the distinction between the collective premium $E[X] + \alpha Var[X]$ with $\alpha = |\ln \varepsilon| / 2u$, where ε denotes the ruin probability in an infinite time horizon and u the initial surplus in a ruin process, (see Bühlmann (1985) or Kaas *et al.* (2001), Chapter 5)), and the distribution between individual contracts of this premium volume by means of an additive premium principle. In this context also the difference between pure risk measures and measures for insolvency risk have to be seen. A risk measure serves the purpose of a collective measure for risk of a sum of risks, while a measure of insolvency risk has to do with addition of marginal risk measures.

Mean value principles rely heavily on mixing distributions, as is demonstrated in the following theorem:

Theorem 2

Suppose that associated with every random variable X there is a unique real number $\rho[X]$, *the risk measure, with the following properties:*

1. $\rho[c] = c$ *for a degenerate risk c*
2. $X \leq_1 Y \Rightarrow \rho[X] \leq \rho[Y]$ *with strict inequality holding unless* $X \equiv_1 Y$.
3. *If* $\rho[X] = \rho[X']$, *Y is a random variable, and I is an independent Bernoulli(t) random variable, then* $\rho[IX + (1-I)Y] = \rho[IX' + (1-I)Y]$.

Then there is a function f, continuous and strictly increasing, such that

$$\rho[X] = f^{-1}\left(\int_{-\infty}^{+\infty} f(x)dF(x)\right)$$

Proof:

(See Goovaerts *et al.* (1984)).

In this situation the assumption 2) of this theorem results in functions f that are strictly increasing. This makes the result less attractive for measurement of insolvency. More attractive then become the assumptions

$$E[X] = E[Y] \text{ and } E[(X-d)_+] \leq E[(Y-d)_+] \quad \forall d$$

which means that there is convex order between X and Y, written $X \leq_{cx} Y$.

As in Kaas *et al.* (2001, Definition 10.6.1) it follows that

$$X \leq_{cx} Y \Rightarrow E[(d-X)_+] \leq E[(d-Y)_+] \quad \forall d$$

such that in addition uniformly heavier lower tails result.

It can be proven that $X \leq_{cx} Y$ if and only if $E[f(X)] \leq E[f(Y)]$ for all convex functions f, provided the expectations exist.

An important special case is the following: $E[X] \leq_{cx} X$ for every random variable X. Therefore, we have $E[f(X)] \geq f[E(X)]$ for every convex function f (Jensen's inequality).

Theorem 3

$\sum X_j \leq_{cx} \sum X_j^c$ *when* X_j^c *is the comonotonic version of* X_j, $J =$ 1,…, n.

Proof

(See Kaas *et al.* ((2001), Theorem 10.6.4)).

Remarks

This result is in line with a 'best practice' approach. Indeed, for a pure risk measure the comonotonic sum is the 'most dangerous' sum. The sum of random variables with an arbitrary dependence structure is less dangerous than the sum of the most dependent variables. This is because in the comonotonic versions of the random variables, all possibilities of hedging have been eliminated.

In addition, for measures of insolvency risk we have that the fatter the tails are, the higher the risk measure. It remains a open question how to define addition of measures. A characterization will be given in the last paragraph.

IV. THE IMPLICATIONS OF IMPOSING GENERAL PROPERTIES FOR ALL RISKS

Let us recall the properties leading to Wang's class of premium principles, (see Wang *et al.* (1997)).

Property 1

For any two risks (non-negative random variables) X and Y we have that $F_X(x) \geq F_Y(x)$ for all $x > 0$ implies $\rho[X] \leq \rho[Y]$.

Property 2

If risks X and Y are comonotonic, then we have $\rho[X+Y] = \rho[X] + \rho[Y]$.

Property 3

If X is the degenerate risk which equals 1 with probability 1, then $\rho[X]=1$.

Property 1 can be weakened to: if $X \leq Y$ with probability one, then $\rho[X] \leq \rho[Y]$. (See Kaas *et al.* (2001), Remark 10.2.4). Properties 2-3 imply that $\rho[aX+b] = a\rho[X]+b$. We recall the following lemma:

Lemma 1

Assume that a risk measure has the properties 1-3. Then there exists an unique distortion function g, which is non-decreasing and has g(0)=0 and g(1)=1, such that for all discrete risks X with only finitely many mass points, we have $\rho[X] = \int_0^\infty g(1 - F_X(x))dx$.

Proof

We give a rather simpler proof than Wang *et* al. Consider a discrete distribution which assigns probability p_j to x_j for $j=1,...,n$. For the inverse distribution function one has

$$F_X^{-1}(p) = x_j \quad \text{for } p_1 + p_2 + ... + p_{j-1} < p < p_1 + p_2 + ... + p_j .$$

Next we consider the two-point inverse distribution:

$$\begin{aligned} F_{X_j}^{-1}(p) &= x_j - x_{j-1} & p > p_0 + ... + p_{j-1} \\ &= 0 & p < p_0 + ... + p_{j-1} \end{aligned}$$

Hence, if U is a uniform random variable, we have

$$F_X^{-1}(U) \stackrel{d}{=} \sum_{j=1}^{n} F_{X_j}^{-1}(U) .$$

From Property 1-2 it is clear that for a two-point risk X with Pr[$X = a$] = q and Pr[$X = 0$] = $1-q$, we have $\rho[X] = av(q)$ where $v(q)$ is a distortion function. On the other hand the right hand side of the above equality in distribution gives:

$$\rho\left[F_X^{-1}(u)\right] = \sum_{j=1}^{n} \rho\left[F_{X_j}^{-1}(u)\right] = \sum_{j=1}^{n} \left(x_j - x_{j-1}\right) g\left(1 - F_X\left(x_{j-1}\right)\right) =$$

$$\int_0^\infty g(1 - F_X(x))dx$$

This completes the proof.

Next let us additionally require additivity of the risk measures (insurance premiums) for sums of independent risks.

Property 4

If the risks X and Y are independent, then we have $\rho[X+Y] = \rho[X] + \rho[Y]$.

Lemma 2

In case properties 1-4 hold, the risk measure reduces to the expectation.

Proof

Consider two independent risks X and Y with $\Pr[X=1] = 1 - \Pr[X=0] = p$ and $\Pr[Y=1] = 1 - \Pr[Y=0] = q$. It is easy to show that for instance $\rho[X+Y] = g(p+q-pq) + g(pq)$. Property 4 then implies:

$$\rho[X] + \rho[Y] = g(q) + g(p) = \rho[X+Y] = g(p+q-pq) + g(pq)$$

Taking the derivative with respect to p gives:

$$g'(p) = g'(p+q-pq)\ (1-q) + g'(pq)q$$

Next let $p \to 0$, then we get $g'(0) = g'(q)(1-q) + g'(0)q$, and hence $g'(q) = g'(0)$. This, together with $g(1)=1$, implies $g(q) = q$ for all q. This proves the stated result, since as is well-known, $E[X] = \int_0^\infty [1 - F_X(x)]dx$.

V. SOLVENCY RISK MEASURES

Here the problem is completely different from the problem of risk measures. We have the situation that one company (or portfolio) A has to be considered embedded into $n-1$ other companies (or portfolios). In case the company A is embedded into $n-1$ very dangerous companies with a very high solvency risk measure, the individual risk measure does not contribute to the same degree to the total solvency requirements as in the case where A is embedded into $n-1$ other companies having almost no solvency requirements calculated on individual basis. It might be that embedding one company into a set of $n-1$ other companies will disturb the solvency requirements, because the global solvency requirements are the constraint. We will formulate the problem as follows by means of an optimization problem.

Practical problem

Assume that the total solvency risk of a conglomerate $X_1 + X_2 + \ldots + X_n$ with n subcompanies is measured by $E((X_1 + X_2 + \ldots X_n - d)_+)$, where in principle all dependencies are possible. The total risk based capital $d_1 + d_2 + \ldots + d_n$ has to be distributed among the daughter companies. Company i has a solvency risk also measured by a stop-loss premium $E((X_i - d_i)_+)$. The ith subcompany only uses the marginal distribution of the risk variable X_i. It is clear that the following subadditivity property holds with probability one (see Kaas *et al.* (2001), Theorem 10.6.4): $(X_1 + ... + X_n - d)_+ \leq \sum_{i=1}^{n} (X_i - d_i)_+$

where $d = d_1 + d_2 + \ldots + d_n$. Because the left hand side only depends on $d_1, \ldots, d_n$ through the sum d, one is of course interested in determining the risk capital in such a way that

Problem A:

$$\underset{\forall d_i}{\text{Min}} \sum_{i=1}^{n} E((X_i - d_i)_+).$$

On the other hand the conglomerate measures the risk by

Problem B:

$$\underset{\overline{X} \in \Gamma}{\text{Max}}\, E((X_1 + X_2 + ... + X_n - d)_+)$$

Here Γ is the set of random vectors with the same marginal distributions as $(X_1, X_2, \ldots, X_n)$.

The following theorem indicates that using a stop-loss retention determined by a VAR approach is the optimal solution to deal with the problem of solvency measurement in connection with the allocation of economic capital.

Theorem 4

$$\underset{\sum d_i = d}{\text{Min}} \sum_{i=1}^{n} E((X_i - d_i)_+) = \underset{\overline{X} \in \Gamma}{\text{Max}}\, E((X_1 + ... + X_n - d)_+),$$

where $d_i = F_{X_i}^{-1}(F_W(d))$, *with* $W = F_{X_1}^{-1}(U) + \ldots + F_{X_n}^{-1}(U)$ *for some uniform variable U.*

Proof

The value of problem A is determined in the following way by means of a Lagrange multiplier:

$$\min_{\lambda, d_1, \ldots, d_n} \sum_{i=1}^{n} E(X_i - d_i)_+ - \lambda(d_1 + \ldots + d_n).$$

Taking the derivative with respect to each d_i gives that for some constant c:

$$F_{X_i}(d_i) = c \Rightarrow d_i = F_{X_i}^{-1}(c)$$

Because $d = \sum_{i=1}^{n} d_i$ one gets $d_i = F_{X_i}^{-1}(F_W(d))$.

Hence $\min_{\sum d_i = d} \sum_{i=1}^{n} E((X_i - d_i)_+) = \sum_{i=1}^{n} E\left(\left(F_{X_i}^{-1}(U) - F_{X_i}^{-1}(F_W(d))\right)_+\right)$

The maximum in the theorem is obtained by means of the theory of comonotonic risks as is shown e.g. in Kaas *et al.* ((2001), Theorem 10.6.4).

Remarks

1. In case everywhere use is made of the stop-loss expression both for all subcompanies and on the conglomerate level, a safe best upper bound is obtained.
2. The VAR plays a very important role, because based on the overall level d the level d_i is determined by means of the VAR.
3. It is clear that direct addition of risk measures, without taking the sum of the characteristics of the total portfolio into account for the subportfolios, is not very realistic.
4. Supervisory authorities, having only the marginal distributions as data, can of course calculate the individual risk measures by using stop-loss premiums. This allows us to compare different companies.
5. Another interpretation is that when a joint treatment of the risk compensation is possible, in case of spreading the risk in different

companies the sum of the risk for insolvency is larger. So one should minimize it.

In convex order all of the possible choices of convex functions v provide the same ordering of risks. In this framework we would like to characterize one special choice of v based on rational allocation of economic capital. For that purpose we consider an extended problem A and B.

Theorem 5

The only convex functions v for which equality holds between

$$A = \underset{\underline{X} \in \Gamma}{\mathrm{Max}}\, E(v((X_1 + X_2 + \ldots + X_n - d)_+) \quad \textit{and}$$

$$B = \underset{d_1 + \ldots + d_n = d}{\mathrm{Min}} \sum_j E(v(X_j - d_j)_+)$$

are given by $v(\chi) = \beta(\chi)$ *for some* >0.

Proof

Let us consider a uniform distribution on $[a,b]$ for X_i, $i = 1,\ldots, n$. Then $F_{X_i}^{-1}(u) = a + (b - a)u$. Because v is a convex function, problem A can be solved immediately, (see Kaas *et al.* (2001), Theorem 10.6.4), giving

$$A = E\left[v\left(na + n(b - a)U - d\right)_+\right]$$

On the other hand, problem B can again be solved by means of a Lagrange multiplier, giving $E(v'(X_j - d_j)) = \lambda$ for all j,

$$\text{or} \quad \frac{1}{b-a} v\left(a + (b-a)u - d_j\right)_+ \Big|_0^1 = \lambda$$

$$\text{or} \quad \frac{1}{b-a}\left[v\left(\left(b - d_j\right)_+\right) - v\left(\left(a - d_j\right)_+\right)\right] = \lambda$$

Hence $d_i = d_j$ for all i and j, and because $d = \sum d_j$ one finds $d_j = \frac{d}{n}$. The value of problem B then equals

$$B = nE\left[v\left(a + (b-a)u - \frac{d}{n}\right)\right].$$

Hence $A=B$ gives:

$$\int_0^1 v\big(na+n(b-a)u-d\big)du = n\int_0^1 v\left(a+(b-a)u-\frac{d}{n}\right)du$$

for every choice $na \le d \le bn$. Taking the derivative on both sides with respect to d and working out the integration over u gives

$$v(nb-d)-v(na-d)=n\,v\left(b-\frac{d}{n}\right)-v\left(a-\frac{d}{n}\right)..$$

Choosing $a=\frac{d}{n}$ leads to $v\,(nb-d)=n\,v\left(b-\frac{d}{n}\right)$.

Now choose $b=\frac{d}{n}+\alpha$, then $v(na) = nv(a)$, and hence $v\big((n+1)a\big) - v(na) = v(a)$.

Taking the derivative with respect to a gives $v'(na) = v'(a)$.

Hence $v'(\alpha)=v'\left(\frac{\alpha}{n}\right)=v'\left(\frac{\alpha}{n^2}\right)=\ldots=v'(0)$, such that $v'(a)$ is a constant, and therefore $v(a) = a\beta$. This proves the stated result.

VI. CONCLUSION

In this paper, we have argued that making use of convexity order leads to a very attractive methodology for determining a risk measure for a cluster of portfolios. As a by-product, we found a consistent criterion for distributing the economic capital between subportfolios. This criterion takes into account dependencies between the risks associated with these subportfolios, without having to specify these dependencies.

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