Overview of Enterprise Risk Management in Insurance

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MASTER PROJECT

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Introduction

At the beginning, firms have been dealing with risks individually. After recognizing the variety of risks, their interaction and the failure in some high profile companies during the 1990's, people started to treat all risks by holistic approach because it gives them a clear picture of the importance and the magnitude of different risks (Lam 2003). Moreover, it can cause a natural hedge that helps companies cut off an unnecessary cost. This approach has been called by different names, e.g., enterprise risk management (ERM), integrated risk management, strategic risk management. Nevertheless, their underlying concepts are very similar. Since actuaries understand and have a lot of experience with risk, they have a great opportunity to expand upon their skill set and to be leader group of future ERM modeler (Bohn and Kemp 2006).

The Casualty Actuarial Society Committee on Enterprise Risk Management defined ERM as the discipline by which an organization in any industry assesses, controls, exploits, finances, and monitors risks from all sources for the purpose of increasing the organization's short- and long-term value to its stakeholders. There were studies suggesting several ways to get better understanding ERM such as getting a more accessible, flexible and holistic view of risk and preventing under- or overestimating risks through the psychological process (Sears and Dorn 2010) and using scenario analysis and stress tests (Guo 2008) based on consideration of extreme events and the company's possible affect to get a more holistic view of the company's risk position and to have the stakeholder understand easier than discussing in mathematical terms (Hull 2010). Nevertheless, people have different attitudes toward risk according to Theory of Plural Rationalities (Ingram and Underwood, 2010) and their view of risk impacts both on their choices and other's (Ingram, 2009). That is why applying knowledge management processes to the implementation of ERM is a better idea (Rodriguez and Edwards 2009)

Risk identification

In order to assessing the enterprise-wide risks, risks should be identified, quantified prioritized, treated and then monitored. The Cognitive Risk Identification and Measurement framework was introduced as an identifying tool that is fast and with limited organizational impact (McGrath 2007). Moreover, by the hierarchical, system-based approach and phylogenetic methodology, a unique and rational classification of risks was obtained (Allen 2010). However, risks are generally classified into four categories: hazard risks, financial risks, operational risks and strategic risks.

Hazard risks

Hazard risks are very familiar for people since they have been recognized and mitigated for a long time. The examples of such risks are risks from natural perils, liability claims, disease and disability, crimes, mortality etc. For mortality risk, it was studied and estimated by predictive model (Edwald et al., 2008). Later, mortality trend risk (broken down into process risk, parameter risk and model risk) was introduced and affected pension plans, life insurers, annuity writers and insurers of workers' compensation, where the tail claims are mostly annuities (Venter, 2010).

Financial risks

Financial risks emerged together with the development of the financial market. There are many studies on this type of risks such as credit risk, market risk, hedging risk. For credit risk, credit portfolio was optimized by multiple credit transition metrics (Han 2008), was modeled and studied its risk factor contributions by using Hoeffding Decomposition (Rosen and Saunders 2009) and its concentration (Reynolds 2009). Moreover, macroeconomics variables were considered as an indicator of healthcare loan/lease portfolio delinquency rate (John et al. 2010) and property casualty insurance companies was suggested to measure, hedge, exploit, and optimize reinsurance credit risk instead of avoiding and controlling their exposure (Bodoff, 2010). Besides, credit derivatives were introduced as a key financial tool in the capital markets for accepting or transferring credit risk (D'Arcy et al. 2009).

For market risk, the importance of the criticality of data management in evolving markets was emphasized for dynamically managing market risk (El-Ramly 2010) and the banks was suggested to manage and hedge market risks in financial system by being the only sector getting into the derivative contracts among banks and provide non-bank companies the products meeting their needs (Chauhan 2010).

For hedging risk, hedge ratio was studied to help determining the returns on the hedge positions. Indian derivative market was investigated and the optimal hedge ratio was estimated based on competing models of which result is better that one from benchmark models (Rao and Thakur 2008)

Furthermore, loss reserve risk is another financial risk that has been studied. A true VaR model of insurance loss reserve risk was developed by economic capital concept (Conway and McCluskey 2006), the evolution of loss reserve risk was examined and the model was built and parameterized by using multiple years of financial statement data (Conway and McCluskey 2008).

For product risk, there are many studies for focus on managing risk in particular insurance product. For example, Multi-Employer Pension Plans was treated by ERM approach to manage the risk effectively (Andrew 2006). Since the rates are measures of the product risk, a re-rating formula was created to calculate proposed rate directly with no need to calculate the previously necessary variables or even to know the current rates (Borogovac 2007). Besides, risk management tool for long liability was also explored and it is found that decomposing the long liability into fixed income and total return components in a market consistent way is a good way to manage (Manistre 2009). A series of warning signs of significant changes in asset prices was introduced based on economic parameters (Cendrowski and Wadecki 2010).

Operational risks

Operational risks are more difficult to be quantified because of human influences. However, there was a study on applying actuarial techniques in operational risk modeling and solving the problems on risk cost allocation and risk mitigation cost-benefit analysis (Mango 2006). The quantification model for this type of risks also has been developed such as applying Lévy copulas to dependence modeling for simple approximations of high quality for multivariate operational VaR (Böcker and Klüppelberg 2007), using analytical-statistical simulation approach in stochastic scenario modeling of operational loss sequences (Olkov and Islamov 2010). Moreover, there are also other studies on operational risk management. For instance, studying operational risk management in local Chinese securities companies (Wang 2007), examining under-evaluating operational VaR in the banking sector (Dionne and Dahen 2008) and reviewing some correlations between the operating income per employee and some elements of company structure (Jacobi 2010).

Risk interrelationship

Understanding risk interrelationships is important for enterprise risk management. Many studied this risk interaction. Interpretive Structural Modeling concepts and techniques were used to help getting a better understanding (Gorvett and Lui 2006). Risk interaction model has been developed. Some started at measuring integrated risk in the portfolio of various assets (Ng and Ma 2007). Fundamental ideas that are necessary to create an integral model of financial risk and operational risk were collected (Acharyya 2007). Interconnectivity of risks in ERM was modeled (Allen et al. 2008). Inter-risk correlation and risk aggregation was analyzed to see interaction between market and credit risks (Böcker and Hillebrand 2008). Later, Bayesian risk aggregation was studied and then the association between the existence of parameter uncertainty and the inter-risk-correlation matrix, which was assessed by Gaussian copula parameters with expert judgment, was found (Boecker et al. 2010).

Risk quantification

To quantify risk, the measuring tool is needed. Stochastic simulation techniques was used to find a risk metric for defined benefit pension plans (Fishbaum and Bergan 2006). Then value-at-risk-based platform was presented to P&C companies to replace ad-hoc method (Freestone et al. 2006). At the same time, a two-dimensional risk measure and iso-risk curves were introduced (Gorvett and Kinsey 2006). Later, market value metrics came up as the only metric that provide information about potential risk exposure of different product features (Harewood et al. 2010). For valuation, market price and appraisal value were suggested to combined in valuation because standalone value are not completely reliable but both of them will provide broader and richer measurement more accurately (Bodoff 2010).

Capital allocation

In order to treat risks, the capital should be allocated properly to optimize stakeholder return according to risk assessing. Financial Rating Risk Replicating techniques were introduced to find capital adequacy by multi-stakeholder approach (Painter and Isaac 2006) and it was used to directly calculate the cost of capital and used as an alternative for capital allocation (McIntyre and Isaac 2006).The economic impact of capital level was also explained (Zhang 2006). However, some still preferred continuing studying on capital allocation. Capital allocation by percentile layers concept was developed and provides a significantly different results from other method such as value-at-risk (Bodoff 2007). Later, capital allocation problems were treated as optimization problem with TVaR constraints (Salam 2010).

ERM model and framework

There was a study showing that the companies that tend to implement ERM if they are more levered, have more volatile earnings and poorer stock market performance and if they appoint a CRO that implies that the values of the CEO's option and stock portfolio is rising in stock volatility (Pagach and Warr 2008). However, stock market performance was found to link with specific characteristics of the firm rather than to the success of ERM (Acharyya 2009). The ERM dashboard was utilized to capture a top-of-the-house view of all risk types (Riebeek 2009). Strategic Objectives at Risk methodology was proposed to increase measurable value to the stakeholder's (Monahan 2009). Business transformation risk management approach was introduced to measure ERM maturity by measure its ability to identify risk, measure impact and define mitigate strategy (Savla 2009). Enterprise risk management framework through strategic allocation of capital was demonstrated. The framework inserted the managerial input into the chanced constraints optimizing model of which outcome tells how to allocate the capital in each period of time (Ai et al. 2011).

Decision making

Although the studies are required more on optimal capital level for an insurer and risk adjusted profitability of business units but the study on application of ERM models in the decision making is also needed (Venter 2008). However, a decision making for solving complex problems was already proposed and presented as the risk assessment tool (Taghavifard et al. 2009).

Example of ERM model by Mathematica 8

The model from Enterprise risk management framework through strategic allocation of capital (Ai et al. 2011) was selected to show in this paper since it was just introduced and the solvency was also considered in the model.

The model is the chance constrained programming model for capital allocation. The objective function is to maximize the expected return over the entire planning period. For each period there are 8 main constraints, which are the followings:

For probabilistic constraints,

- Project and financial risk constraints to ensure the risk within the firm's project risk appetite and financial risk appetite (in percentage). The firm must have a balance both in the project investment and the portfolio of financial assets.
- Operational risk constraint follows the standardize approach of Basel II. The operational risk factors for projects and financial assets, risk limit and firm's operational risk appetite (in percentage) are given.
- Hazard risk constraint
- Solvency constraint requires that the returns in the last period are sufficient to repay any financial obligation due at the end of the period.

For deterministic constraints,

- Strategic or Regulatory constraint such as maximum investment in financial assets or minimum investment in real projects
- Range and budget constraint

The model will be assigned for the given number of period and, at the beginning of every period, the objective function and the constraints inputs will be changed based on the new information at that time. Also, the number of constraint will be reduced. Only the constraints of the left periods will be considered.

The following is the output from Mathematica with in the same input as in the original paper. However, the technique mentioned (Charnes and Cooper 1963) in the original one was not applied because of insufficient understanding. Then the suggested genetic algorithm was studied (Poojari and Varghese 2008). Unfortunately, with the limited of time, this algorithm was not applied to the model. The probabilistic constraints were converted into deterministic ones by central limit theorem under normality condition.

Parameters

```
In[1]:= μ = .01; σ = .01; Σ1 = {{.001, .000632, .001225, .000274, -2.5 x 10^-5, 0},
   {.000632, .04, .006197, .001732, -.00016, 0}, {.001225, .006197, .15,
    .003354, -.00031, 0}, {.000274, .001732, .003354, .03, -.00027, 0},
   {-2.5 x 10^-5, -.00016, -.00031, -.00027, .00025, 0}, {0, 0, 0, 0, 0, σ}};
 Σ2 = {{.002, .001095, .002, .0005, -3.9 x 10^-5, 0},
   {.001095, .06, .008764, .002739, -.00021, 0},
   {.002, .008764, .2, .005, -.00039, 0}, {.0005, .002739, .005, .05, -.00077, 0},
   {-3.9 x 10^-5, -.00021, -.00039, -.00077, .0003, 0}, {0, 0, 0, 0, 0, σ}};
 r1 = {1.08, 1.2, 1.6, 1.12, 1.038, μ};
 r2 = {1.06, 1.18, 1.3, 1.08, 1.04, μ};
 α = {.05, .05, .05, .05, .0008};
 r_P0 = 0; r_A0 = 0; l_op = 0.2; l_h = 0.01; d_1 = .02; d_2 = .3; γ_P = .2; γ_A = .1; γ_S = .5; c = .7;
 rate1 = {r_S11P, r_S12P, r_LP, r_S11A, r_S12A, h1}; rate2 = {r_S21P, r_S22P, r_LP, r_S21A, r_S22A, h2};
 w_1 = {w_S11P, w_S12P, w_LP, w_S11A, w_S12A, u1, w_S21P, w_S22P, w_S21A, w_S22A, u2};
 D_1 = MultinormalDistribution[r1, Σ1]; D_2 = MultinormalDistribution[r2, Σ2];
```

Optimizing at Period 1

```
obj1 = Expectation [( w1[[1]] * rate1[[1]] + w1[[2]] * rate1[[2]] +
        w1[[4]] * rate1[[4]] + w1[[5]] * rate1[[5]] - w1[[6]] * .2 * .01) *
      ( w1[[7]] * rate1[[1]] + w1[[8]] * rate1[[2]] + w1[[9]] * rate1[[4]] +
        w1[[10]] * rate1[[5]] - w1[[11]] * .2 * .01) + w1[[3]] * rate1[[3]], rate1 ≈ D1]

[4]= 4. × 10^-6 u1 u2 + 1.6 wLP - 0.00224 u2 wS11A - 0.00216 u2 wS11P - 0.002076 u2 wS12A -
  0.0024 u2 wS12P - 0.00224 u1 wS21A + 1.2844 wS11A wS21A + 1.20987 wS11P wS21A +
  1.16229 wS12A wS21A + 1.34573 wS12P wS21A - 0.00216 u1 wS21P + 1.20987 wS11A wS21P +
  1.1674 wS11P wS21P + 1.12102 wS12A wS21P + 1.29663 wS12P wS21P - 0.002076 u1 wS22A +
  1.16229 wS11A wS22A + 1.12102 wS11P wS22A + 1.07769 wS12A wS22A + 1.24544 wS12P wS22A -
  0.0024 u1 wS22P + 1.34573 wS11A wS22P + 1.29663 wS11P wS22P + 1.24544 wS12A wS22P + 1.48 wS12P wS22P

5]:= con1E = Expectation[w1[[1]] * rate1[[1]] + w1[[2]] * rate1[[2]], rate1 ≈ D1];
con1v = Expectation[(w1[[1]] * rate1[[1]] + w1[[2]] * rate1[[2]] - con1E)^2, rate1 ≈ D1];
con1 = 0 <= Expand[InverseCDF[NormalDistribution[0, 1], α[[1]]] * √con1v + con1E];

con2E = Expectation[w1[[4]] * rate1[[4]] + w1[[5]] * rate1[[5]], rate1 ≈ D1]; con2v =
 Expectation[(w1[[4]] * rate1[[4]] + w1[[5]] * rate1[[5]] - con2E)^2, rate1 ≈ D1];
con2 = 0 <= Expand[InverseCDF[NormalDistribution[0, 1], α[[2]]] * √con2v + con2E];

con3E =
 Expectation[γP * (w1[[1]] * rate1[[1]] + w1[[2]] * rate1[[2]] + w1[[3]] * rate1[[3]]) +
   γA * (w1[[4]] * rate1[[4]] + w1[[5]] * rate1[[5]]), rate1 ≈ D1]; con3v =
 Expectation[(γP * (w1[[1]] * rate1[[1]] + w1[[2]] * rate1[[2]] + w1[[3]] * rate1[[3]]) +
     γA * (w1[[4]] * rate1[[4]] + w1[[5]] * rate1[[5]]) - con3E)^2, rate1 ≈ D1]; con3 =
 0.2 >= Expand[InverseCDF[NormalDistribution[0, 1], 1 - α[[3]]] * √con3v + con3E];

con4E = Expectation[(1 - w1[[6]]) * rate1[[6]], rate1 ≈ D1];
con4v = Expectation[((1 - w1[[6]]) * rate1[[6]] - con4E)^2, rate1 ≈ D1]; con4 =
 0.01 >= Expand[InverseCDF[NormalDistribution[0, 1], 1 - α[[4]]] * √con4v + con4E];

con5E = Expectation[(1 - γP) * (w1[[1]] * rate1[[1]] + w1[[2]] * rate1[[2]]) -
    γP * w1[[3]] * rate1[[3]] + (1 - γA) * (w1[[4]] * rate1[[4]] + w1[[5]] * rate1[[5]]) -
    (1 - u1) * h1 - u1 (1 + 0.2) * .01, rate1 ≈ D1];
con5v = Expectation[((1 - γP) * (w1[[1]] * rate1[[1]] + w1[[2]] * rate1[[2]]) -
      γP * w1[[3]] * rate1[[3]] + (1 - γA) * (w1[[4]] * rate1[[4]] + w1[[5]] * rate1[[5]]) -
      (1 - w1[[6]]) * rate1[[6]] - w1[[6]] * (1 + 0.2) * .01 - con5E)^2, rate1 ≈ D1];
con5 = 0.7 <= Expand[InverseCDF[NormalDistribution[0, 1], α[[5]]] * √con5v + con5E];

con6 = w1[[1]] + w1[[2]] + w1[[3]] + w1[[4]] + w1[[5]] + w1[[6]] * (1 + .2) * .01 ≤ 1;
con7 = w1[[1]] + w1[[2]] + w1[[3]] ≥ 0.5;

con81 = w1[[1]] ≥ 0; con82 = w1[[2]] ≥ 0; con83 = w1[[3]] ≥ 0;
con84 = w1[[4]] ≥ 0; con85 = w1[[5]] ≥ 0; con86 = 1 ≥ w1[[6]] ≥ 0;
cOn6 = w1[[7]] + w1[[8]] + w1[[9]] + w1[[10]] + w1[[11]] * (1 + .2) * .01 ≤ 1;
cOn7 = w1[[7]] + w1[[8]] ≥ 0.5;

cOn81 = w1[[7]] ≥ 0; cOn82 = w1[[8]] ≥ 0; cOn83 = w1[[9]] ≥ 0;
cOn84 = w1[[10]] ≥ 0; cOn85 = 1 ≥ w1[[11]] ≥ 0;
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```
ϵ = Expectation[ w1[[1]] * rate1[[1]] + w1[[2]] * rate1[[2]] +
    w1[[4]] * rate1[[4]] + w1[[5]] * rate1[[5]] - w1[[6]] * .2 * .01, rate1 ≈ D1];
cOn1E = Expectation[ϵ * (w1[[7]] * rate1[[1]] + w1[[8]] * rate1[[2]]) +
    w1[[3]] * rate1[[3]], rate1 ≈ D1]; cOn1v = Expectation[
   (ϵ * (w1[[7]] * rate1[[1]] + w1[[8]] * rate1[[2]]) + w1[[3]] * rate1[[3]] - cOn1E) ^2,
   rate1 ≈ D1];
cOn1 = 0 <= Expand[InverseCDF[NormalDistribution[0, 1], α[[1]]] * √cOn1v + cOn1E];
cOn2E = Expectation[ϵ * (w1[[9]] * rate1[[4]] + w1[[10]] * rate1[[5]]), rate1 ≈ D1];
cOn2v = Expectation[
   (ϵ * (w1[[9]] * rate1[[4]] + w1[[10]] * rate1[[5]]) - cOn2E) ^2, rate1 ≈ D1];
cOn2 = 0 <= Expand[InverseCDF[NormalDistribution[0, 1], α[[2]]] * √cOn2v + cOn2E];
cOn3E = Expectation[
   γP * ϵ * (w1[[7]] * rate1[[1]] + w1[[8]] * rate1[[2]] + w1[[3]] * rate1[[3]]) + γA * ϵ *
     (w1[[9]] * rate1[[4]] + w1[[10]] * rate1[[5]]), rate1 ≈ D1]; cOn3v = Expectation[
   (γP * ϵ * (w1[[7]] * rate1[[1]] + w1[[8]] * rate1[[2]] + w1[[3]] * rate1[[3]]) + γA *
       ϵ * (w1[[9]] * rate1[[4]] + w1[[10]] * rate1[[5]]) - cOn3E) ^2, rate1 ≈ D1]; cOn3 =
  0.2 ϵ >= Expand[InverseCDF[NormalDistribution[0, 1], 1 - α[[3]]] * √cOn3v + cOn3E];
cOn4E = Expectation[(1 - w1[[11]]) * rate1[[6]], rate1 ≈ D1];
cOn4v = Expectation[((1 - w1[[11]]) * rate1[[6]] - cOn4E) ^2, rate1 ≈ D1]; cOn4 =
  0.01 >= Expand[InverseCDF[NormalDistribution[0, 1], 1 - α[[4]]] * √cOn4v + cOn4E];
cOn5E = Expectation[(1 - γP) * ϵ * (w1[[7]] * rate1[[1]] + w1[[8]] * rate1[[2]]) -
    γP * w1[[3]] * rate1[[3]] + (1 - γA) * ϵ * (w1[[9]] * rate1[[4]] + w1[[10]] * rate1[[5]]) -
    ϵ * (1 - w1[[11]]) * rate1[[6]] - ϵ * w1[[11]] * (1 + 0.2) * .01,
   rate1 ≈ D1]; cOn5v = Expectation[
   ((1 - γP) * ϵ * (w1[[7]] * rate1[[1]] + w1[[8]] * rate1[[2]]) - γP * w1[[3]] * rate1[[3]] +
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       (1 - γA) * ϵ * (w1[[9]] * rate1[[4]] + w1[[10]] * rate1[[5]]) - ϵ * (1 - w1[[11]]) *
        rate1[[6]] - ϵ * w1[[11]] * (1 + 0.2) * .01 - cOn5E) ^2, rate1 ≈ D1]; cOn5 =
  0.7 ϵ <= Expand[InverseCDF[NormalDistribution[0, 1], α[[5]]] * √cOn5v + cOn5E];
```

```
In[22]:= FindMaximum[{obj1, con1, con2, con3, con4, con5, con6,
          con7, con81, con82, con83, con84, con85, con86, cOn1, cOn2, cOn3,
          cOn4, cOn5, cOn6, cOn7, cOn81, cOn82, cOn83, cOn84, cOn85}, w1]

Out[22]= {1.24162, {WS11P → 0.188127, WS12P → 0.359353, WLP → 6.62258 × 10^-9,
          WS11A → 0.249321, WS12A → 0.191887, u1 → 0.942691, WS21P → 0.188128,
          WS22P → 0.359353, WS21A → 0.249321, WS22A → 0.191887, u2 → 0.94269}}
```

Output at different percentage of long project investment

```
In[23]:= FindMaximum[{obj1, con1, con2, con3, con4, con5, con6, con7,
           con81, con82, con83, con84, con85, con86, cOn1, cOn2, cOn3, cOn4,
           cOn5, cOn6, cOn7, cOn81, cOn82, cOn83, cOn84, cOn85, wLP ≥ 0.01}, w1]
Out[23]= {1.23883, {wS11P → 0.217864, wS12P → 0.332375, wLP → 0.01,
           wS11A → 0.229711, wS12A → 0.198737, u1 → 0.942689, wS21P → 0.161165,
           wS22P → 0.35791, wS21A → 0.250131, wS22A → 0.219482, u2 → 0.942689}}
In[24]:= FindMaximum[{obj1, con1, con2, con3, con4, con5, con6, con7,
           con81, con82, con83, con84, con85, con86, cOn1, cOn2, cOn3, cOn4,
           cOn5, cOn6, cOn7, cOn81, cOn82, cOn83, cOn84, cOn85, wLP ≥ 0.001}, w1]
Out[24]= {1.24134, {wS11P → 0.191107, wS12P → 0.356661, wLP → 0.00100012,
           wS11A → 0.247365, wS12A → 0.192554, u1 → 0.942699, wS21P → 0.185419,
           wS22P → 0.359221, wS21A → 0.249411, wS22A → 0.194636, u2 → 0.942699}}
In[25]:= FindMaximum[{obj1, con1, con2, con3, con4, con5, con6, con7,
           con81, con82, con83, con84, con85, con86, cOn1, cOn2, cOn3, cOn4,
           cOn5, cOn6, cOn7, cOn81, cOn82, cOn83, cOn84, cOn85, wLP ≥ 0.0001}, w1]
Out[25]= {1.24159, {wS11P → 0.188425, wS12P → 0.359084, wLP → 0.00010009,
           wS11A → 0.249126, wS12A → 0.191953, u1 → 0.942705, wS21P → 0.187846,
           wS22P → 0.359341, wS21A → 0.249332, wS22A → 0.192168, u2 → 0.942704}}
```

Optimizing at Period 2

```
         wS11P2 = Extract[weight1[[1]], 2]; wS12P2 = Extract[weight1[[2]], 2];
         wLP2 = Extract[weight1[[3]], 2]; wS11A2 = Extract[weight1[[4]], 2];
         wS12A2 = Extract[weight1[[5]], 2]; u21 = Extract[weight1[[6]], 2];
Out[34]= 0.942691
In[35]:= w2 = {wS11P2, wS12P2, wLP2, wS11A2, wS12A2, u21, wS21P2, wS22P2, wS21A2, wS22A2, u22}
Out[35]= {0.188127, 0.359353, 6.62258 × 10^-9, 0.249321,
           0.191887, 0.942691, wS21P2, wS22P2, wS21A2, wS22A2, u22}
In[56]:= obj2 = Expectation[
           ( w2[[1]] * r1[[1]] + w2[[2]] * r1[[2]] + w2[[4]] * r1[[4]] + w2[[5]] * r1[[5]] - w2[[6]] *
              .2 * .01) * ( w2[[7]] * rate2[[1]] + w2[[8]] * rate2[[2]] + w2[[9]] * rate2[[4]] +
             w2[[10]] * rate2[[5]] - w2[[11]] * .3 * .01) + w2[[3]] * rate2[[3]], rate2 ≈ D2]
Out[56]= 8.60935 × 10^-9 - 0.0033328 u22 + 1.19981 wS21A2 + 1.17759 wS21P2 + 1.15537 wS22A2 + 1.3109 wS22P2
In[37]:= ϵ2 = w2[[1]] * r1[[1]] + w2[[2]] * r1[[2]] +
           w2[[4]] * r1[[4]] + w2[[5]] * r1[[5]] - w2[[6]] * .2 * .01
Out[37]= 1.11093
```

```
In[110]:= cO2n1E = Expectation[ϵ2 * (w2[[7]] * rate2[[1]] + w2[[8]] * rate2[[2]]) +
      w2[[3]] * rate2[[3]], rate2 ≈ D2]; cO2n1v = Expectation[
     (ϵ2 * (w2[[7]] * rate2[[1]] + w2[[8]] * rate2[[2]]) + w2[[3]] * rate2[[3]] - cO2n1E) ^2,
     rate2 ≈ D2]; cO2n1 =
    0 <= Expand[InverseCDF[NormalDistribution[0, 1], α[[1]]] * √cO2n1v + cO2n1E];
   cO2n2E = Expectation[ϵ2 * (w2[[9]] * rate2[[4]] + w2[[10]] * rate2[[5]]), rate2 ≈ D2];
   cO2n2v = Expectation[
     (ϵ2 * (w2[[9]] * rate2[[4]] + w2[[10]] * rate2[[5]]) - cO2n2E) ^2, rate2 ≈ D2];
   cO2n2 = 0 <= Expand[
       InverseCDF[NormalDistribution[0, 1], α[[2]]] * √cO2n2v + cO2n2E];
   cO2n3E = Expectation[γP * ϵ2 * (w2[[7]] * rate2[[1]] +
          w2[[8]] * rate2[[2]] + w2[[3]] * rate2[[3]]) +
      γA * ϵ2 * (w2[[9]] * rate2[[4]] + w2[[10]] * rate2[[5]]), rate2 ≈
      D2]; cO2n3v = Expectation[
     (γP * ϵ2 * (w2[[7]] * rate2[[1]] + w2[[8]] * rate2[[2]] + w2[[3]] * rate2[[3]]) +
        γA * ϵ2 * (w2[[9]] * rate2[[4]] + w2[[10]] * rate2[[5]]) - cO2n3E) ^2, rate2 ≈ D2];
   cO2n3 = 0.2 ϵ2 >= Expand[InverseCDF[NormalDistribution[0, 1], 1 - α[[3]]] * √cO2n3v +
       cO2n3E];
   cO2n4E = Expectation[(1 - w2[[11]]) * rate2[[6]], rate2 ≈ D1]; cO2n4v =
    Expectation[((1 - w2[[11]]) * rate2[[6]] - cO2n4E) ^2, rate2 ≈ D2]; cO2n4 = 0.01 >=
     Expand[InverseCDF[NormalDistribution[0, 1], 1 - α[[4]]] * √cO2n4v + cO2n4E];
   cO2n5E = Expectation[(1 - γP) * ϵ2 * (w2[[7]] * rate2[[1]] + w2[[8]] * rate2[[2]]) - γP *
       w2[[3]] * rate2[[3]] + (1 - γA) * ϵ2 * (w2[[9]] * rate2[[4]] + w2[[10]] * rate2[[5]]) -
      ϵ2 * (1 - w2[[11]]) * rate2[[6]] - ϵ2 * w2[[11]] * (1 + 0.2) * .01,
     rate2 ≈ D2]; cO2n5v = Expectation[
     ((1 - γP) * ϵ2 * (w2[[7]] * rate2[[1]] + w2[[8]] * rate2[[2]]) - γP * w2[[3]] * rate2[[3]] +
        (1 - γA) * ϵ2 * (w2[[9]] * rate2[[4]] + w2[[10]] * rate2[[5]]) - ϵ2 * (1 - w2[[11]]) *
         rate2[[6]] - ϵ2 * w2[[11]] * (1 + 0.2) * .01 - cO2n5E) ^2, rate2 ≈ D2]; cO2n5 =
    0.7 ϵ2 <= Expand[InverseCDF[NormalDistribution[0, 1], α[[5]]] * √cO2n5v + cO2n5E];
   cO2n6 = w2[[7]] + w2[[8]] + w2[[9]] + w2[[10]] + w2[[11]] * (1 + .3) * .01 ≤ 1;
   cO2n7 = w2[[7]] + w2[[8]] ≥ 0.5;

   cO2n81 = w2[[7]] ≥ 0; cO2n82 = w2[[8]] ≥ 0; cO2n83 = w2[[9]] ≥ 0;
   cO2n84 = w2[[10]] ≥ 0; cO2n85 = 1 ≥ w2[[11]] ≥ 0;
```

```
In[118]:= {max2, weight2} = FindMaximum[{obj2, cO2n1, cO2n2, cO2n3, cO2n4, cO2n5, cO2n6, cO2n7,
      cO2n81, cO2n82, cO2n83, cO2n84, cO2n85}, {wS21P2, wS22P2, wS21A2, wS22A2, u22}]

Out[118]= {1.19331, {wS21P2 → 0.197355, wS22P2 → 0.302649,
      wS21A2 → 0.0852235, wS22A2 → 0.402518, u22 → 0.942693}}
```

Compare the result to the original paper result

Decision Variable	The original paper	Mathematica 8				
		No condition	0.0001 in LP	0.001 in LP	0.01 in LP	0.0181 in LP
Stage 1						
Investment in manufacturing project 1 in period 1	0.5801	0.1881	0.1884	0.1911	0.2179	0.2422
Investment in manufacturing project 2 in period 1	0.1237	0.3594	0.3591	0.3567	0.3324	0.3100
Investment in R&D project in period 1(LP)	0.0181	0.000000007	0.0001	0.0010	0.0100	0.0181
Investment in the index fund in period 1	0.0466	0.2493	0.2491	0.2474	0.2297	0.2143
Investment in the Treasury bill in period 1	0.2190	0.1919	0.1920	0.1926	0.1987	0.2040
The proportion of hazard risk insured in period1	0.9479	0.9427	0.9427	0.9427	0.9427	0.9427
Investment in manufacturing project 1 in period 2	0.2409	0.1881	0.1878	0.1854	0.1611	0.1514
Investment in manufacturing project 2 in period 2	0.3363	0.3594	0.3593	0.3592	0.3579	0.3487
Investment in the index fund in period 2	0.0720	0.2493	0.2493	0.2494	0.2501	0.2599
Investment in the Treasury bill in period 2	0.3383	0.1919	0.1922	0.1946	0.2195	0.2287
The proportion of hazard risk insured in period2	0.9479	0.9427	0.9427	0.9427	0.9427	0.9427
Optimal Return	1.1797	1.2416	1.2416	1.2413	1.2388	1.2365
Stage 2						
Investment in manufacturing project 1 in period 2	0.4996	0.1976	0.1974	0.1978	0.2016	0.2052
Investment in manufacturing project 2 in period 2	0.1682	0.3026	0.3026	0.3022	0.2984	0.2948
Investment in the index fund in period 2	0.0365	0.0852	0.0852	0.0851	0.0842	0.0833
Investment in the Treasury bill in period 2	0.2822	0.4025	0.4025	0.4026	0.4035	0.4044
The proportion of hazard risk insured in period2	0.9479	0.9427	0.9427	0.9469	0.9427	0.9427
Optimal Return	1.1356	1.1933	1.1933	1.1929	1.1895	1.1863

Optimal decision (column group heading spanning "The original paper" and "Mathematica 8")

The results are different from the one in the original paper. The two short-term project investments and one of the financial investments go in the opposite direction. It also suggests investing in the long-term project in very small proportion. However, the optimal return from Mathematica is higher.

Conclusion

Since risk interrelationship is important in risk integration, multivariate probability comes to play an important role in ERM. Copula was introduced and studied with the dependence structure models in insurance (e.g. Schirmacher 2008). However, the application of the models still needs the advanced stochastic programming. The chance constrained optimizing problems which can be solved right now are under the normal distribution because of the need of the central limit theorem for the conversion to deterministic constraint. Moreover, most of the popular risk measures are in form of probability. Therefore, by ERM goal which is maximizing the stakeholders return, advanced stochastic programming would be a great tool to achieve the goal by treating such risk measures as constraints.

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