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## Exercise 1

Given a world in which there are only two risky assets  $S_1$  and  $S_2$ , with respective expected returns.

$$\bar{R}_1 = 0.1 = \frac{10}{100}, \quad \bar{R}_2 = 0.18 = \frac{18}{100}$$

and variances and covariances given by

$$\sigma_1^2 = 0.016 = \frac{16}{10000}, \quad \sigma_{12}^2 = 0.016 = \frac{16}{10000}, \quad \sigma_2 = 0.01 = \frac{1}{100}$$

where the opportunity set in

$(\bar{R}, \sigma)$  space

The Market Price of Risk ( **MPR**) is given by

$$\theta = \frac{\bar{R}_{AC} - R_B}{\sigma_{AC}} \quad (1)$$

From (1), the MPR is thus:

$$\theta = \frac{\sqrt{49728}}{168}$$

$$\implies x_1 = \frac{13}{21}, \quad x_2 = \frac{8}{21}$$

And the Mean Return  $\bar{R}_\pi$  is given in the equation

$$\bar{R}_\pi = \lambda_1 \bar{R}_1 + \lambda_2 \bar{R}_2 \text{ where } \lambda \text{ is the number of shares and } \bar{R} \text{ is the return} \quad (2)$$

Thus

$$\begin{aligned}
\bar{R}_\pi &= \lambda \bar{R}_1 + (1 - \lambda) \bar{R}_2 \\
&= \frac{10}{100} \lambda + (1 - \lambda) \frac{18}{100} \\
&= \frac{18}{100} - \frac{8\lambda}{100} \\
&= \frac{1}{50} (9 - 4\lambda)
\end{aligned}$$

The correlation between two asset investments is given by equation (3).

$$\rho_{12} = \frac{\sigma_{12}}{\sigma_1 \sigma_2} \quad (3)$$

and the Risk of Investment is given by

$$\sigma_\pi^2 = \lambda_1^2 \sigma_1^2 + 2\lambda_1 \sigma_1 \lambda_2 \sigma_2 \rho_{12} + \lambda_2^2 \sigma_2^2 \quad (4)$$

From (4)

$$\begin{aligned}
\sigma_\pi^2 &= \lambda^2 \left( \frac{16}{1000} \right) + 2\lambda(1 - \lambda) \left( \frac{16}{1000} \right) + \lambda^2 \left( \frac{1}{100} \right) \\
&= \frac{1}{100} \left[ \frac{16\lambda^2}{100} + (2\lambda - 2\lambda^2) \left( \frac{16}{100} \right) + 1 - 2\lambda + \lambda^2 \right] \\
&= \frac{1}{10000} [16\lambda^2 + 32\lambda - 32\lambda^2 + 100 - 200\lambda + 100\lambda^2] \\
&= \frac{1}{10000} [84\lambda^2 - 168\lambda + 100]
\end{aligned}$$

but

$$\lambda = \frac{-50\bar{R}_\pi + 9}{4}$$

$$\begin{aligned}
\therefore \sigma_\pi^2 &= \frac{1}{10000} \left[ 84 \left( \frac{-50\bar{R}_\pi + 9}{4} \right) - 168 \left( \frac{-50\bar{R}_\pi + 9}{4} \right) + 100 \right] \\
&= \frac{1}{10000} \left[ \frac{84}{16} (81 - 900\bar{R}_\pi^2 + 25000\bar{R}_\pi^2) - \frac{1512 + 8400\bar{R}_\pi + 400}{4} \right] \\
&= \frac{1}{4 \times 4} [210000\bar{R}_\pi^2 - 42000\bar{R}_\pi + 2356] \\
\therefore \sigma_\pi^2 &= \frac{1}{400} [21,000\bar{R}_\pi^2 - 42,000\bar{R}_\pi + 2356]^{\frac{1}{2}}
\end{aligned}$$

Given  $R_0 = 0.06 = \frac{6}{100}$  and from (1)

$$\begin{aligned}
\Rightarrow \theta &= \frac{12 - 8\lambda}{\sqrt{84\lambda^2 - 168\lambda + 100}} \\
&= (12 - \lambda)(84\lambda^2 - 168\lambda + 100)^{\frac{1}{2}}
\end{aligned}$$

To minimize the risk, we differentiate  $\theta$  w.r.t.  $\lambda$ .

$$\begin{aligned}\frac{d\theta}{d\lambda} &= (-8)(84\lambda^2 - 168\lambda + 100)^{-\frac{1}{2}} - \frac{1}{2} [(12 - \lambda)(168\lambda - 168)(84\lambda^2 - 168\lambda + 100)^{-1}] = 0 \\ &= (84\lambda^2 - 168\lambda + 100)^{-\frac{1}{2}} [-8 - (6 - 4\lambda)(168\lambda - 168)(84\lambda^2 - 168\lambda + 100)^{-1}] = 0\end{aligned}$$

$$\begin{aligned}(84\lambda^2 - 168\lambda + 100)^{-\frac{1}{2}} &= 0 \quad \text{or} \\ -8 - (6 - 4\lambda)(168\lambda - 168)(84\lambda^2 - 168\lambda + 100)^{-1} &= 0\end{aligned}$$

$$\begin{aligned}-172\lambda^2 + 1344\lambda - 800 - 1008\lambda + 1008 + 672\lambda^2 - 672\lambda &= 0 \\ -336\lambda + 208 &= 0\end{aligned}$$

$$\begin{aligned}\lambda &= \frac{208}{336} \\ \lambda &= \frac{13}{31}\end{aligned}$$

$$\begin{aligned}\therefore \theta &= \frac{12 - \lambda}{\sqrt{84\lambda^2 + 168\lambda + 100}} \\ &= \frac{12 - \frac{13}{31}}{\sqrt{84\left(\frac{13}{31}\right)^2 - 168\left(\frac{13}{31}\right) + 100}} \\ &= \frac{7.0476}{\sqrt{28.190476}} \\ &= \frac{7.0476}{5.3094} \\ &= 1.327367\end{aligned}$$

Thus

$$\begin{aligned}\bar{R} &= \theta\sigma + R_0 \\ &= 1.327367\sigma + 0.06\end{aligned}$$

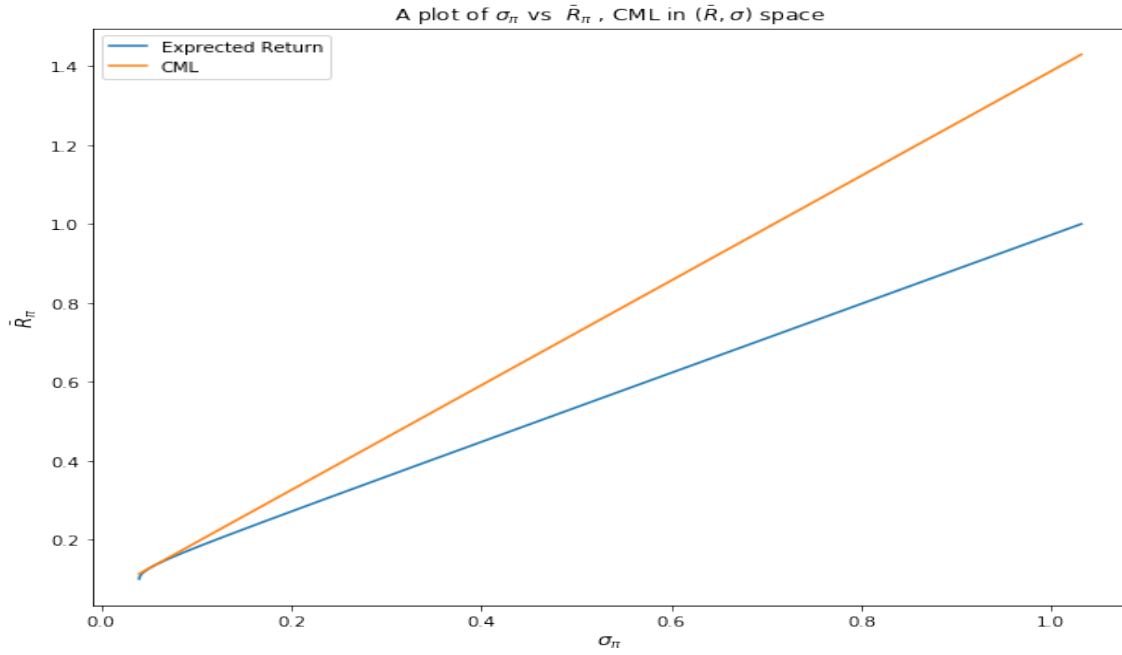


Figure 1: The opportunity set in  $(\bar{R}, \sigma)$  space and the efficient frontier

## Exercise 2

Considering a situation where there are three risky assets  $S_1, S_2$  and  $S_3$  with respective expected returns

$$\bar{R}_1 = 0.09 = \frac{9}{100}, \quad \bar{R}_2 = 0.11 = \frac{11}{100}, \quad \bar{R}_3 = 0.17 = \frac{17}{100}$$

whilst the variances and covariances are given by

$$\sigma_1^1 = 0.016 = \frac{16}{10000}, \quad \sigma_{12}^2 = 0.016 = \frac{16}{10000}, \quad \sigma_{13}^2 = 0, \quad \sigma_2 = 0.01 = \frac{1}{100}, \quad \sigma_{23}^2 = 0.012 = \frac{12}{10000}, \quad \sigma_3^2 = 0.0144 = \frac{144}{10000},$$

If we suppose that the risk free rate  $R_0 = 0.05 = \frac{5}{100}$  and short selling and borrowing are allowed.

Therefore,

$$\sigma_{i,j} = \begin{pmatrix} 16 & 16 & 0 \\ 16 & 100 & 12 \\ 0 & 12 & 144 \end{pmatrix}$$

$$\begin{pmatrix} \sigma, 1, 1 & \sigma 1, 2 & \sigma 1, 3 \\ \sigma 2, 1 & \sigma 2, 2 & \sigma 2, 3 \\ \sigma 3, 1 & \sigma 3, 2 & \sigma 3, 3 \end{pmatrix} \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix} = \begin{pmatrix} \bar{R}_1 - R_0 \\ \bar{R}_2 - R_0 \\ \bar{R}_3 - R_0 \end{pmatrix}$$

$$\begin{pmatrix} 16 & 16 & 0 \\ 16 & 100 & 12 \\ 0 & 12 & 144 \end{pmatrix} \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix} = \begin{pmatrix} \bar{R}_1 - R_0 \\ \bar{R}_2 - R_0 \\ \bar{R}_3 - R_0 \end{pmatrix}$$

$$\begin{pmatrix} 16 & 16 & 0 \\ 16 & 100 & 12 \\ 0 & 12 & 144 \end{pmatrix} \begin{pmatrix} z_1 \\ z_2 \\ z_3 \end{pmatrix} = \begin{pmatrix} 4 \\ 6 \\ 12 \end{pmatrix}$$

$$z_1 = \frac{79}{332}, \quad z_2 = \frac{1}{83}, \quad z_3 = \frac{41}{490}$$

Afterwards, we find the value of  $\lambda$  as follows

however,

$$z_1 + z_2 + z_3 = \lambda \tag{5}$$

from (5)

$$\begin{aligned} \lambda &= \frac{79}{332} + \frac{1}{83} + \frac{41}{490} \\ &= \frac{331}{996}
\end{aligned}$$

Then we proceed to find the values of  $x_i$  s.t.  $\forall i \in \{3\}$

$$\begin{aligned} x_1 &= \frac{z_1}{\lambda} = \frac{237}{331} \\ x_2 &= \frac{z_2}{\lambda} = \frac{12}{331} \\ x_3 &= \frac{z_3}{\lambda} = \frac{82}{331}
\end{aligned}$$

It therefore follows that:

$$x_1 + x_2 + x_3 = 1 \text{ Proved.}$$

The Mean of Return  $\bar{R}_\pi$  is thus

$$\begin{aligned}\bar{R}_\pi &= x_1\lambda_1 + x_2\lambda_2 + x_3\lambda_3 \\ &= \frac{237}{331} \frac{132}{3300} + \frac{12}{331} \frac{11}{100} + \frac{82}{331} \frac{17}{100} \\ &= 0.1105 = 11.05\%\end{aligned}$$

$$\begin{aligned}\sigma_\pi^2 &= x_1^2\lambda_1^2 + 2\lambda_1x_1\lambda_2x_2\rho_{12} + x_2^2\lambda_2^2 + 2x_2\lambda_2x_3\lambda_3\rho_{23} + x_3^2\lambda_3^2 \\ &= 0.00082 + 0.00083 + 0.000013 + 0.000022 + 0.00088 \\ \therefore \sigma_\pi &= 0.04268 \quad \text{after taking square root of both sides}\end{aligned}$$

We find the Shape Ratio as follows

$$\theta = \frac{\bar{R}_\pi - R_0}{\sigma_\pi} \tag{6}$$

From (6)

$$\begin{aligned}\implies \theta &= \frac{0.1105 - 0.05}{\sqrt{0.0001822}} \\ &= 1.1475 \approx 1.418\end{aligned}$$

### Exercise 3

A pension fund manager requires an expected return of  $R\%$  with minimum risk on an investment in two risky assets  $S_1$  and  $S_2$  with respective expected returns

$$\bar{R}_1 = 0.06 = \frac{6}{100}, \quad \bar{R}_2 = 0.08 = \frac{8}{100}$$

with variances and covariances (scaled by  $10^4$ ) given by

$$\sigma_1^2 = 1, \quad \sigma_{12}^2 = 2, \quad \sigma_2^2 = 2$$

we note that

$$\begin{aligned}\lambda_1 + \lambda_2 &= 1 \\ \implies \lambda_1 + \lambda_2 - 1 &= 0\end{aligned}$$

Expected return is

$$\begin{aligned}\bar{R}_\pi &= x_1\lambda_1 + x_2\lambda_2 \\ &= 6\lambda_1 + 8\lambda_2 \\ \implies 6\lambda_1 + 8\lambda_2 - R &= 0\end{aligned}$$

Risk of Investment

$$\begin{aligned}\sigma_{\pi}^2 &= \lambda_1^2 \sigma_1^2 + 2\lambda_1 \sigma_1 \lambda_2 \sigma_2 \rho_{12} + \lambda_2^2 \sigma_2^2 \\ &= \lambda_1^2 + 4\lambda_1 \lambda_2 \sigma_{12} + 2\lambda_2^2\end{aligned}$$

$$\mathcal{L}(\lambda_1, \lambda_2, \alpha, \beta) = \lambda_1^2 + 4\lambda_1 \lambda_2 \sigma_{12} + 2\lambda_2^2 + \alpha(\lambda_1 + \lambda_2 - 1) + \beta(6\lambda_1 + 8\lambda_2 - R)$$

We Take the partial derivatives of  $\lambda_1, \lambda_2, \alpha, \beta$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \lambda_1} &= 2\lambda_1 + 4\lambda_2 + \alpha + 6\beta = 0 \\ &= 2\lambda_1 + 4\lambda_2 = -\alpha - 6\beta\end{aligned}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \lambda_2} &= 4\lambda_1 + 4\lambda_2 + \alpha + 8\beta = 0 \\ &= 4\lambda_1 + 4\lambda_2 = -\alpha - 8\beta\end{aligned}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \alpha} &= \lambda_1 + \lambda_2 - 1 = 0 \\ &= \lambda_1 + \lambda_2 = 1\end{aligned}$$

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \beta} &= 6\lambda_1 + 8\lambda_2 - R = 0 \\ &= 6\lambda_1 + 8\lambda_2 = R\end{aligned}$$

Using the partial derivatives  $\frac{\partial \mathcal{L}}{\partial \lambda_1}, \frac{\partial \mathcal{L}}{\partial \lambda_2}$  we form the following system of equations.

$$2\lambda_1 + 4\lambda_2 = -\alpha - 6\beta \quad (7)$$

$$4\lambda_1 + 4\lambda_2 = -\alpha - 8\beta \quad (8)$$

where

$$2\lambda_1 = -2\beta \implies \lambda_1 = -\beta$$

and

$$4\lambda_2 = -\alpha - 4\beta$$

$$\lambda_2 = -\frac{1}{4}\alpha - \beta$$

using the other system partial derivatives of  $\alpha, \beta$  we derive the following system of linear simultaneous equations.

$$\lambda_1 + \lambda_2 = 1 \quad (9)$$

$$6\lambda_1 + 8\lambda_2 = R \quad (10)$$

$$\begin{aligned}
-6\beta + 8\left(\frac{-1}{4}\alpha - \beta\right) &= R \\
-2\alpha - 14\beta &= R
\end{aligned}$$

from (7), we substitute for  $\lambda_1$  and  $\lambda_2$ .

$$\begin{aligned}
-\beta + \frac{-1}{4}\alpha - \beta &= 1 \\
\frac{-1}{4}\alpha - 2\beta &= 1 - \alpha - 8\beta &= 4 \\
\therefore -2\alpha - 14\beta &= R &\text{..... c} \\
-\alpha - 8\beta &= 4 &\text{..... d}
\end{aligned}$$

For (c) - 2(d)  $\implies$

$$\begin{aligned}
2\beta &= R - 8 \\
\therefore \beta &= \frac{R}{2} - 4
\end{aligned}$$

Also from (d)

$$\begin{aligned}
-\alpha - \left(8\frac{R}{2} - 4\right) &= 4 \\
-\alpha - 4R + 32 &= 4 \\
-\alpha - 4R &= -28 \\
\alpha &= 28 - 4R
\end{aligned}$$

$$\begin{aligned}
\therefore \lambda_1 &= -\beta \\
\implies \lambda_1 &= -\left(\frac{R}{2} - 4\right)
\end{aligned}$$

$$\text{For } \lambda_1 \geq 0 \quad \frac{R}{2} \leq 4 \quad \implies R \leq 8$$

Also

$$\begin{aligned}
\lambda_2 &= -\beta - \frac{\alpha}{4} \\
&= \left(\frac{\alpha}{2}\right) - \frac{1}{4}(28 - 4R) \\
&= 4 - \frac{R}{2} - \frac{28}{4} + R \\
\lambda_2 &= \frac{R}{2} - 3
\end{aligned}$$

$$\text{For } \lambda_2 \geq 0, \quad \frac{R}{2} \geq 3, \quad R \geq 6.$$

$$\therefore 6 \leq R \leq 8$$

The condition sufficiently satisfy the constraint that prohibits short selling.



## Exercise 4

(a)

$$P(R \leq -t) = 1 - c \quad (11)$$

After substituting  $R$  in (11) we obtain the follow:

$$\begin{aligned} P(Q \times X \leq -t) &= 1 - c \\ P(Q\{\mu + \sigma\mathcal{N}(0, 1)\} \leq -t) &= 1 - c \\ P(\mu + \sigma\mathcal{N}[0, 1] \leq -\frac{t}{Q}) &= 1 - c \\ P(\mathcal{N}(0, 1) \leq -\frac{t}{Q\sigma} - \frac{\mu}{\sigma}) &= 1 - c \\ \Phi\left(-\left(\frac{t}{Q\sigma} + \frac{\mu}{\sigma}\right)\right) &= 1 - c \\ 1 - \Phi\left(\left(\frac{t}{Q\sigma} + \frac{\mu}{\sigma}\right)\right) &= 1 - c \\ \Phi\left(\left(\frac{t}{Q\sigma} + \frac{\mu}{\sigma}\right)\right) &= c \\ \frac{t}{\sigma Q} + \frac{\mu}{\sigma} &= \Phi^{-1}(c) \end{aligned}$$

$$\begin{aligned} \text{However } \Phi^{-1}(-t) &= 1 - \Phi(t) \quad t + Q\mu = Q\sigma\Phi^{-1}(c) \\ \therefore t &= Q\left(\sigma\Phi^{-1}(c) - \mu\right) \end{aligned}$$

Thus proved.

- (b) The mean and variance for Netflix over the period (2017, 1, 1) to (2020, 1, 1) and the 1-day Value at Risk at the 95% confidence level of an investment of 1,000\$.

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Value-at-Risk: \$36.878877

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Mean is: \$0.0015091

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Variance is: \$0.023338  
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