ECON 337901
FINANCIAL ECONOMICS

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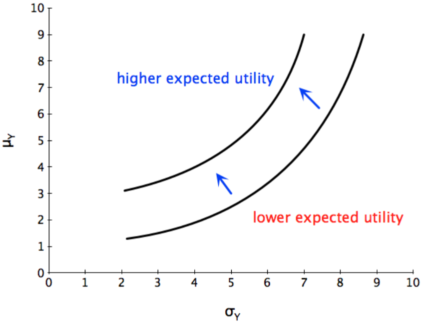
Justifying Mean-Variance Utility



But what does the "budget constraint" look like in this diagram? To see, we need to consider the gains from diversification.

The Gains From Diversification

One of the most important lessons that we can take from modern portfolio theory involves the gains from diversification.

To see where these gains come from, consider forming a portfolio from two risky assets:

$$\tilde{r}_1,\, \tilde{r}_2 = \text{random returns}$$

$$\mu_1,\, \mu_2 = \text{expected returns}$$

$$\sigma_1,\, \sigma_2 = \text{standard deviations}$$

Assume $\mu_1 > \mu_2$ and $\sigma_1 > \sigma_2$ to create a trade-off between expected return and risk if the investor must choose between one or the other.

The Gains From Diversification

If w is the fraction of initial wealth allocated to asset 1 and $1 - w$ is the fraction of initial wealth allocated to asset 2, the random return $\tilde{r}_P$ on the portfolio is

$$\tilde{r}_P = w\tilde{r}_1 + (1 - w)\tilde{r}_2$$

and the expected return μ_P on the portfolio is

$$\begin{aligned} \mu_P &= E[w\tilde{r}_1 + (1 - w)\tilde{r}_2] \\ &= wE(\tilde{r}_1) + (1 - w)E(\tilde{r}_2) \\ &= w\mu_1 + (1 - w)\mu_2 \end{aligned}$$

The Gains From Diversification

$$\mu_P = w\mu_1 + (1 - w)\mu_2$$

The expected return on the portfolio is a weighted average of the expected returns on the individual assets, where the weights in the average are the portfolio weights.

Since $\mu_1 > \mu_2$, μ_P can range from μ_2 up to μ_1 as w increases from zero to one. Even higher (or lower) expected returns are possible if short selling is allowed.

The Gains From Diversification

But now let's calculate the variance of the random portfolio return

$$\tilde{r}_P = w\tilde{r}_1 + (1-w)\tilde{r}_2$$

$$\mu_P = w\mu_1 + (1-w)\mu_2$$

$$\begin{aligned}
\sigma_P^2 &= E[(\tilde{r}_P - \mu_P)^2] \\
&= E\{[w\tilde{r}_1 + (1-w)\tilde{r}_2 - w\mu_1 - (1-w)\mu_2]^2\} \\
&= E\{[w(\tilde{r}_1 - \mu_1) + (1-w)(\tilde{r}_2 - \mu_2)]^2\}
\end{aligned}$$

The Gains From Diversification

$$\sigma_P^2 = E\{[w(\tilde{r}_1 - \mu_1) + (1 - w)(\tilde{r}_2 - \mu_2)]^2\}$$

But remember:

$$(x + y)^2 \neq x^2 + y^2$$

Instead, use the "FOIL" rule:

$$\begin{aligned}(x + y)^2 &= (x + y)(x + y) \\ &= x^2 + xy + yx + y^2 \\ &= x^2 + 2xy + y^2\end{aligned}$$

The Gains From Diversification

$$\sigma_P^2 = E\{[w(\tilde{r}_1 - \mu_1) + (1-w)(\tilde{r}_2 - \mu_2)]^2\}$$

$$(x+y)^2 = x^2 + 2xy + y^2$$

$$\begin{aligned}
\sigma_P^2 \quad = \quad & E[w^2(\tilde{r}_1 - \mu_1)^2 + (1-w)^2(\tilde{r}_2 - \mu_2)^2 \\
& + 2w(1-w)(\tilde{r}_1 - \mu_1)(\tilde{r}_2 - \mu_2)]
\end{aligned}$$

The Gains From Diversification

$$\begin{aligned}\sigma_P^2 &= E[w^2(\tilde{r}_1 - \mu_1)^2 + (1-w)^2(\tilde{r}_2 - \mu_2)^2 \\ &\quad + 2w(1-w)(\tilde{r}_1 - \mu_1)(\tilde{r}_2 - \mu_2)]\end{aligned}$$

$$\begin{aligned}\sigma_P^2 &= w^2 E[(\tilde{r}_1 - \mu_1)^2] + (1-w)^2 E[(\tilde{r}_2 - \mu_2)^2] \\ &\quad + 2w(1-w) E[(\tilde{r}_1 - \mu_1)(\tilde{r}_2 - \mu_2)]\end{aligned}$$

The Gains From Diversification

In probability theory, the covariance between two random variables X_1 and X_2 is defined as

$$\sigma(X_1, X_2) = E\{[X_1 - E(X_1)][X_2 - E(X_2)]\}$$

and the correlation between X_1 and X_2 is defined as

$$\rho(X_1, X_2) = \frac{\sigma(X_1, X_2)}{\sigma(X_1)\sigma(X_2)}$$

The Gains From Diversification

The covariance

$$\sigma(X_1, X_2) = E\{[X_1 - E(X_1)][X_2 - E(X_2)]\}$$

is positive if

$$X_1 - E(X_1) \text{ and } X_2 - E(X_2)$$

tend to have the same sign, negative

$$X_1 - E(X_1) \text{ and } X_2 - E(X_2)$$

tend to have opposite signs, and zero if

$$X_1 - E(X_1) \text{ and } X_2 - E(X_2)$$

show no tendency to have the same or opposite signs.

The Gains From Diversification

Mathematically, therefore, the covariance

$$\sigma(X_1, X_2) = E\{[X_1 - E(X_1)][X_2 - E(X_2)]\}$$

measures the extent to which the two random variables tend to move together.

Economically, buying two assets with returns that are imperfectly, and especially, negatively correlated is like buying insurance: one return will be high when the other is low and vice versa, reducing the overall risk of the portfolio.

The Gains From Diversification

The correlation

$$\rho(X_1, X_2) = \frac{\sigma(X_1, X_2)}{\sigma(X_1)\sigma(X_2)}$$

has the same sign as the covariance, and is therefore also a measure of co-movement.

But "scaling" the covariance by the two standard deviations makes the correlation range between -1 and 1:

$$-1 \leq \rho(X_1, X_2) \leq 1$$

The Gains From Diversification

Hence

$$\begin{aligned}\sigma_P^2 &= w^2 E[(\tilde{r}_1 - \mu_1)^2] + (1-w)^2 E[(\tilde{r}_2 - \mu_2)^2] \\ &\quad + 2w(1-w)E[(\tilde{r}_1 - \mu_1)(\tilde{r}_2 - \mu_2)]\end{aligned}$$

implies

$$\begin{aligned}\sigma_P^2 &= w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_{12} \\ &= w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2\rho_{12}\end{aligned}$$

where

$\sigma_{12} =$ the covariance between $\tilde{r}_1$ and $\tilde{r}_2$

$\rho_{12} =$ the correlation between $\tilde{r}_1$ and $\tilde{r}_2$

The Gains From Diversification

This is the source of the gains from diversification: the expected portfolio return

$$\mu_P = w\mu_1 + (1-w)\mu_2$$

is a weighted average of the expected returns on the individual asset returns, but the standard deviation of the portfolio return

$$\sigma_P = [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2\rho_{12}]^{1/2}$$

is not a weighted average of the standard deviations of the returns on the individual assets and can be reduced by choosing a mix of assets ($0 < w < 1$) when ρ_{12} is less than one and, especially, when ρ_{12} is negative.

The Gains From Diversification

To see more specifically how this works, start with the case where $\rho_{12} = 1$ so that the individual asset returns are perfectly correlated. With $\rho_{12} = 1$,

$$\begin{aligned}
\sigma_P &= [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2\rho_{12}]^{1/2} \\
&= [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2]^{1/2} \\
&= [x^2 + y^2 + 2xy]^{1/2} = [(x+y)^2]^{1/2}
\end{aligned}$$

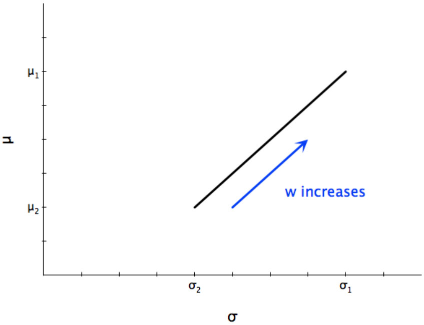
The Gains From Diversification

With $\rho_{12} = 1$,

$$\begin{aligned}
\sigma_P &= [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2\rho_{12}]^{1/2} \\
&= [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2]^{1/2} \\
&= \{[w\sigma_1 + (1-w)\sigma_2]^2\}^{1/2} \\
&= |w\sigma_1 + (1-w)\sigma_2|.
\end{aligned}$$

In this special case, the standard deviation of the return on the portfolio is a weighted average of the standard deviations of the returns on the individual assets.

The Gains From Diversification



When $\rho_{12} = 1$, so that individual asset returns are perfectly correlated, there are no gains from diversification.

The Gains From Diversification

Next, let's consider the opposite extreme, in which $\rho_{12} = -1$ so that the individual asset returns are perfectly, but negatively, correlated:

$$\begin{aligned}
\sigma_P &= [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2\rho_{12}]^{1/2} \\
&= [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 - 2w(1-w)\sigma_1\sigma_2]^{1/2} \\
&= [x^2 + y^2 - 2xy]^{1/2} = [(x-y)^2]^{1/2}
\end{aligned}$$

The Gains From Diversification

With $\rho_{12} = -1$,

$$\begin{aligned}\sigma_P &= [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2\rho_{12}]^{1/2} \\ &= [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 - 2w(1-w)\sigma_1\sigma_2]^{1/2} \\ &= \{[w\sigma_1 - (1-w)\sigma_2]^2\}^{1/2} \\ &= |w\sigma_1 - (1-w)\sigma_2|.\end{aligned}$$

In this special case, the gains from diversification are so strong that it is possible to create a "synthetic" risk free portfolio!

The Gains From Diversification

With $\rho_{12} = -1$,

$$\sigma_P = |w\sigma_1 - (1 - w)\sigma_2|.$$

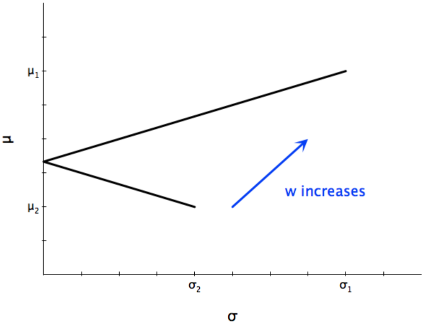
To achieve $\sigma_P = 0$, choose w so that

$$w\sigma_1 - (1 - w)\sigma_2 = 0$$

$$w\sigma_1 = \sigma_2 - w\sigma_2$$

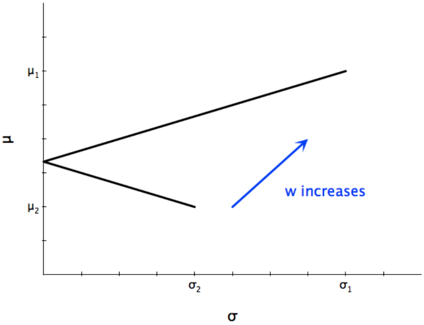
$$w = \frac{\sigma_2}{\sigma_1 + \sigma_2}$$

The Gains From Diversification



When $\rho_{12} = -1$, so that individual asset returns are perfectly, but negatively correlated, risk can be eliminated via diversification.

The Gains From Diversification



When $\rho_{12} = -1$, even the most risk-averse investor will still want to allocate some of his or her funds to the "high risk" asset 1.

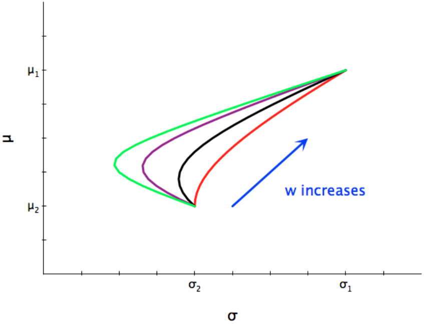
The Gains From Diversification

$$\mu_P = w\mu_1 + (1-w)\mu_2$$

$$\sigma_P = [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2\rho_{12}]^{1/2}$$

In all intermediate cases, there will still be gains from diversification. These gains will become stronger as ρ_{12} declines from 1 to -1.

The Gains From Diversification



As ρ_{12} decreases from 0.5 to 0 to -0.5 to -0.75, the gains from diversification strengthen.

The Gains from Diversification

$$\tilde{r}_p = w\tilde{r}_1 + (1-w)\tilde{r}_2$$

$$\mu_P = w\mu_1 + (1-w)\mu_2$$

$$\sigma_P = [w^2\sigma_1^2 + (1-w)^2\sigma_2^2 + 2w(1-w)\sigma_1\sigma_2\rho_{12}]^{1/2}$$

PS12, Q1: Suppose $\mu_1 = 8$, $\mu_2 = 4$, $\sigma_1 = 8$, and $\sigma_2 = 4$. Calculate μ_p and σ_p for various values of w when $\rho_{12} = 0$ and $\rho_{12} = -0.5$. The gains from diversification are strongest when ρ_{12} is negative, but still present whenever $\rho_{12} < 1$.