Portfolios

BUSI 721: Data-Driven Finance I

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Portfolio returns

- Two assets, prices p_1 and p_2
- Own shares x_1 and x_2
- Portfolio value is $p_1 x_1 + p_2 x_2$
- Fraction of value in asset i (**weight of asset**) is

$$w_i = \frac{p_i x_i}{p_1 x_1 + p_2 x_2}$$

- Future prices + dividends $\Rightarrow$ returns r_1 and r_2
- Portfolio return is $w_1 r_1 + w_2 r_2$.

Example

- $\$200$ in asset 1 and $\$300$ in asset 2
- asset 1 goes up 10% and asset 2 goes up 5%
- asset 1 $\mapsto \$220$
- asset 2 $\mapsto \$315$
- portfolio value is $\$535$
- This is a 7% gain and

$$\frac{2}{5} \times 0.1 + \frac{3}{5} \times 0.05 = 0.07$$

Expected return

- Returns are random variables
- Expected = mean
- mean portfolio return $w_1 r_1 + w_2 r_2$ is

$$w_1 \times \text{mean of } r_1 + w_2 \times \text{mean of } r_2$$

Variance

- The variance of the portfolio return is

$$w_1^2\sigma_1^2 + w_2\sigma_2^2 + 2w_1w_2\rho\sigma_1\sigma_2$$

- where σ_i = std dev of r_i and ρ is the correlation of r_1 and r_2.
- Lower correlation implies lower portfolio risk!

Proof of variance formula

- Variance is expected squared deviation from mean
- Set $r_p = w_1 r_1 + w_2 r_2$ and use overbars to denote means
- Variance of r_p is

$$\text{mean of } (r_p - \bar{r}_p)^2$$

- And

$$r_p - \bar{r}_p = w_1 r_1 + w_2 r_2 - (w_1 \bar{r}_1 + w_2 \bar{r}_2)$$

- So

$$r_p - \bar{r}_p = w_1 (r_1 - \bar{r}_1) + w_2 (r_2 - \bar{r}_2)$$

- To square this, use
  $(a+b)^2 = a^2$
  $+ b^2 + 2ab$

- So portfolio variance is

$$w_1^2 \times \text{mean of } (r_1 - \bar{r}_1)^2$$

$$+w_2^2 \times \text{mean of } (r_2 - \bar{r}_2)^2$$

$$+2w_1w_2 \times \text{mean of } (r_1 - \bar{r_1})(r_2 - \bar{r}_2)$$

- This is

$$w_1^2\sigma_1^2 + w_2\sigma_2^2 + 2w_1w_2\rho\sigma_1\sigma_2$$

Example

In [2]:

```python
mu1, mu2 = 0.06, 0.1
sigma1, sigma2 = 0.2, 0.3
rho = 0.3
w1, w2 = 0.4, 0.6
```

In [3]:

```
import numpy as np

mn = w1*mu1 + w2*mu2
var = w1**2*sigma1**2 + w2**2*sigma2**2 + 2*w1*w2*rho*sigma1*sigma2

print(f"mean portfolio return is {mn:.2%}")
print(f"std dev of portfolio return is {np.sqrt(var):.2%}")
```

```
mean portfolio return is 8.40%
std dev of portfolio return is 21.78%
```

Simulation

In [4]:

```
cov = [
    [sigma1**2, rho*sigma1*sigma2],
    [rho*sigma1*sigma2, sigma2**2]
]

from scipy.stats import multivariate_normal as multinorm
rets = multinorm.rvs(
    mean=[mu1, mu2],
    cov=cov,
    size=1000000
)
rp = w1*rets[:,0] + w2*rets[:,1]

print(f"simulated mean is {np.mean(rp):.2%}")
print(f"simulated std dev is {np.std(rp):.2%}")
```

```
simulated mean is 8.39%
simulated std dev is 21.77%
```

Cash

- Adding cash (money market investment) to a portfolio has a simple effect on expected return and risk.
- Let asset 2 be cash. Its return has negligible risk. Call its return r_{mm}.
- Portfolio mean is $w_1\mu_1 + w_2 r_{mm}$
- Portfolio variance is $w_1^2\sigma_1^2$
- Portfolio std dev is $w_1\sigma_1$.

Margin loans

- You can have negative cash by borrowing from your broker.
- Example: put $\$1{,}000$ in an account, borrow $\$200$ and buy $\$1{,}200$ of a stock.
- Continue to call asset 2 cash.
- Your portfolio weights are

$w_1 = 1.2$ and $w_2 = -0.2$.

- Your expected return is $1.2 \times \mu_1 - 0.2 \times r_{ml}$ where r_{ml} is the margin loan rate.
- Your std dev is $1.2\sigma_1$.

Short selling

- You can have a negative weight on a stock by selling short.
- To sell short, your broker borrows shares on your behalf and sells them.
- You eventually have to buy the shares back in the market and return them.
- Profit by selling high and buying low.
- Example: short sell 100 shares \$100 stock.
    - Stock falls to \$90 and you cover the short (buy and return shares).
    - Paid \$90 and sold at \$100 $\Rightarrow$ profit \$10 per share on 100 shares.

Long and short returns (simplified version)

- Assume we invest $\$1{,}000$, short sell $\$400$ of stock 2 and buy $\$1{,}400$ of stock 1.
- The weights are 1.4 in stock 1 and -0.4 in stock 2.
- Suppose stock 1 goes up 10% and stock 2 goes up 5%.
    - Stock 1 $\rightarrow \$1{,}540$.
    - Stock 2 position $\rightarrow -\$420$.
    - Portfolio value $\rightarrow \$1{,}120 = 12\%$ return
    - $w_1 r_1 + w_2 r_2 = 1.4 \times 0.10 - 0.4 \times 0.05$
      $= 0.12$

Long and short returns (practical version)

- Proceeds from short sales are retained as collateral
- Investor may get some interest on the proceeds while they are held (called short interest rebate)
- We can invest $\$1{,}000$, short sell $\$400$ of stock 2 and buy $\$1{,}400$ of stock 1 only if we take out a margin loan for $\$400$.
- Actual return in example is

$$1.4 \times 0.10 - 0.4 \times 0.05$$

$$-0.4 \times r_{ml} + 0.4 \times r_{sir} - 0.4 \times \text{ short borrowing fee}$$

- where r_{sir} is the short interest rebate rate.

Enhanced index return example

- Invest $\$1,000$. Borrow $\$1,000$ on margin loan.
- Buy $\$1,000$ of SPY and buy $\$1,000$ of CVX.
- Short sell $\$1,000$ of COP.
- Return is SPY return + CVX return - COP return minus margin loan/short interest rebate/short borrowing fee drag.
- If CVX beats COP enough, you will beat SPY.

More assets

- n stocks
- weights $w_1, \ldots, w_n$
- expected returns $\mu_1, \ldots, \mu_n$
- covariance matrix Σ
    - diagonal elements of covariance matrix are variances
    - off-diagonal elements are correlation $\times$ std dev $\times$ std dev.

Portfolio risk

- Portfolio variance is $w'\Sigma w$
- Portfolio std dev is $\sqrt{w'\Sigma w}$

In [5]:

```
# example

w = np.array([0.2, 0.2, 0.4])
sigma1, sigma2, sigma3 = 0.2, 0.3, 0.1
rho12, rho13, rho23 = 0.3, 0.5, 0.4

cov = np.array([
    [sigma1**2, rho12*sigma1*sigma2, rho13*sigma1*sigma3],
    [rho12*sigma1*sigma2, sigma2**2, rho23*sigma2*sigma3],
    [rho13*sigma1*sigma3, rho23*sigma2*sigma3, sigma3**2]
])
stdev = np.sqrt(w @ cov @ w)

print(f"portfolio std dev is {stdev:.2%}")
```

```
portfolio std dev is 10.84%
```

Portfolio expected return

- If $w_i \geq 0$ and sum to 1, then portfolio mean is $w'\mu$.
- If $w_i \geq 0$ and sum to less than 1, then portfolio mean is

$$w'\mu + \left(1 - \sum w_i\right) r_{mm}$$

- If $w_i \geq 0$ and sum to more than 1, then portfolio mean is

$$w'\mu + \left(1 - \sum w_i\right) r_{ml}$$

- So we can say that if $w_i \geq 0$, then portfolio mean is

$$w'\mu + \left(1 - \sum w_i\right) r_f$$

- where $r_f = r_{mm}$ if cash > 0 and $r_m = r_{ml}$ if cash < 0.
- With short sales, portfolio mean is also

$$w'\mu + \left(1 - \sum w_i\right) r_f$$

- minus the drag from difference between margin loan and short interest rebate rates and minus short borrowing fees.

In [6]:

```
# continuing prior example

rf = 0.04
mu1, mu2, mu3 = 0.1, 0.12, 0.08
mu = np.array([mu1, mu2, mu3])

port_mean = w @ mu + (1-np.sum(w))*rf
print(f"portfolio mean is {port_mean:.2%}")
```

```
portfolio mean is 8.40%
```

Estimating from historical returns

- Example:
  - SPY = S&P 500
  - IEF = Treasury bonds
  - GLD = gold
- Get adjusted closing prices from Yahoo
- Compute returns as percent changes

In [7]:
```python
import yfinance as yf

tickers = ["SPY", "IEF", "GLD"]
prices = yf.download(tickers, start="1970-01-01")["Adj Close"]
rets = prices.pct_change().dropna()
rets.head(3)
```

```
[*********************100%%**********************]  3 of 3 completed
```

Out[7]:

	GLD	IEF	SPY
Date			
2004-11-19	0.009013	-0.005480	-0.011117
2004-11-22	0.003796	0.000704	0.004769
2004-11-23	-0.004449	-0.000938	0.001526

In [8]:
```
rets.corr()
```

Out[8]:

	GLD	IEF	SPY
GLD	1.000000	0.208371	0.049425
IEF	0.208371	1.000000	-0.320228
SPY	0.049425	-0.320228	1.000000

Annualizing

- May be easier to interpret means and std devs when expressed in annual terms
- Annualize daily means by multiplying by 252 (# of trading days in a year)
- Annualize daily variances by multiplying by 252
- Annualize daily std devs by multiplying by square root of 252

In [9]:

```python
print(f"annualized means are \n{252*rets.mean()}")
print(f"\nannualized std devs are \n{np.sqrt(252)*rets.std()}")
```

```
annualized means are
GLD    0.090313
IEF    0.031442
SPY    0.106698
dtype: float64

annualized std devs are
GLD    0.176744
IEF    0.068225
SPY    0.193171
dtype: float64
```

Portfolio returns

In [10]:

```python
w = np.array([0.2, 0.3, 0.5])
mean = w @ rets.mean()
var = w @ rets.cov() @ w
stdev = np.sqrt(var)

print(f"annualized mean portfolio return is {252*mean:.2%}")
print(f"annualized std dev is {np.sqrt(252)*stdev:.2%}")
```

```
annualized mean portfolio return is 8.08%
annualized std dev is 10.18%
```