The Consumption Capital Asset Pricing Model

Instructor: Dmytro Hryshko
Readings


- Mehra and Prescott (2003), The Equity Premium in Retrospect, Handbook of the Economics of Finance, Elsevier. **Chapter 14.**
The Representative Agent Hypothesis and its Notion of Equilibrium

- An infinitely-lived **Representative Agent**
  - Helps avoid terminal period problem
  - Equivalence with finite lives if operative bequest motive
  - In complete markets, representative agent is the one whose utility function is a weighted average of the utilities of all the economy’s participants

- **No Trade Equilibrium**
  - Positive net supply: the representative agent willingly holds total supply
  - Zero net supply: at the prevailing price, supply = demand = 0
An Exchange (Endowment) Economy. Lucas 1978

- **Recursive trading**: many periods (one period in CAPM); investment decisions are made one period at a time, taking due account of their impact on the future state of the world
- **One perfectly divisible share**
- **Dividend** = economy’s total output, $Y_t$
- Output arises exogenously and stochastically (fruit tree) and is perishable
- Stationary stochastic process for $Y_t$
Transition probability matrix (TPM)

E.g., the 3-state TPM

\[
T = \begin{pmatrix}
\pi_{11} & \pi_{12} & \pi_{13} \\
\pi_{21} & \pi_{22} & \pi_{23} \\
\pi_{31} & \pi_{32} & \pi_{33}
\end{pmatrix}
\]

with \(\pi_{ij}\)-th element denoting Prob(\(Y_{t+1} = Y^j|Y_t = Y^i\)), and \(Y^j\) is output in state \(j\).

- Lucas fruit tree
- Rational expectations economy: knowledge of the economy’s structure and the stochastic process
The problem

\[ \max_{\{z_{t+1}\}} \mathbb{E} \left( \sum_{t=0}^{\infty} \delta^t U(\tilde{c}_t) \right) \]

s.t. \( c_t + p_t z_{t+1} \leq z_t Y_t + p_t z_t \)
\( z_t \leq 1, \text{ all } t \)

F.O.C:

\[
\begin{align*}
U'(c_t)p_t &= \delta \mathbb{E}_t U'(\tilde{c}_{t+1}) (\tilde{p}_{t+1} + \tilde{Y}_{t+1}) \text{ or } \\
U'(c_t(Y^i))p_t(Y^i) &= \delta \sum_j \pi_{ij} U'(c_{t+1}(Y^j)) \left[ p_{t+1}(Y^j) + Y_{t+1}(Y^j) \right]
\end{align*}
\]

utility loss from purchasing 1 unit of sec. at \( t \)

expected utility gain at \( t + 1 \) from liquidating the proceeds and consuming
Definition of an equilibrium. \( U'(c_t)p_t = \delta E_t U'(\tilde{c}_{t+1})(\tilde{p}_{t+1} + \tilde{Y}_{t+1}) \)

For the entire economy to be in equilibrium, it must, therefore, be true that:

1. \( z_t = z_{t+1} = z_{t+2} = \ldots = 1 \) — the representative agent owns the entire security
2. \( c_t = Y_t \) — ownership of the entire security entitles the agent to all the economy’s output
3. FOC is satisfied — the agents’ holdings of the security are optimal given the prevailing prices

(1)–(3) imply

\[
U'(Y_t)p_t = \delta E_t U'(\tilde{Y}_{t+1})(\tilde{p}_{t+1} + \tilde{Y}_{t+1})
\]
Example

Assume utility is $U(c) = \log c$, $\delta = 0.96$, the 3-state economy, $(Y^1, Y^2, Y^3) = (3/2, 1, 1/2)$. The TPM is

$$T = \begin{pmatrix}
\frac{1}{2} & \frac{1}{4} & \frac{1}{4} \\
\frac{1}{4} & \frac{1}{2} & \frac{1}{4} \\
\frac{1}{4} & \frac{1}{4} & \frac{1}{2}
\end{pmatrix}$$

Denote $p(Y^i) = p(i)$, then

$$\frac{2}{3} = U'[c(Y^1)] = \sum_j \pi_{1j} U'[c(j)]Y(j)$$

$$1p(2) = 0.96 + 0.96 \left[ \frac{1}{6}p(1) + \frac{1}{2}p(2) + \frac{1}{2}p(3) \right]$$

$$2p(3) = 0.96 + 0.96 \left[ \frac{1}{6}p(1) + \frac{1}{4}p(2) + 1p(3) \right]$$

Solving the system yields $p(1) = 36, p(2) = 24, p(3) = 12$. 
Equilibrium pricing

\[ U'(Y_t)p_t = \delta E_t U'(\tilde{Y}_{t+1})(\tilde{p}_{t+1} + \tilde{Y}_{t+1}) \]

\[ E_t[U'(Y_{t+1})p_{t+1}] = E_t \left[ E_{t+1}\delta U'(Y_{t+2})Y_{t+2} + E_{t+1}\delta U'(Y_{t+2})p_{t+2} \right] \]

\[ = E_t\delta U'(Y_{t+2})Y_{t+2} + E_t\delta U'(Y_{t+2})p_{t+2} \]

by law of iterated expectations

\[ E_t\delta U'(Y_{t+1})p_{t+1} = E_t\delta^2 U'(Y_{t+2})Y_{t+2} + E_t\delta^2 U'(Y_{t+2})p_{t+2} \]

\[ U'(Y_t)p_t = E_t\delta U'(Y_{t+1})Y_{t+1} + E_t\delta^2 U'(Y_{t+2})Y_{t+2} + E_t\delta^2 U'(Y_{t+2})p_{t+2} \]

\[ \vdots \]

\[ U'(Y_t)p_t = E_t \sum_{j=1}^{\infty} \delta^j U'(\tilde{Y}_{t+j})\tilde{Y}_{t+j} + E_t \lim_{k \to \infty} \delta^k U'(Y_{t+k})p_{t+k} \]

must be=0
Equilibrium pricing

\[ p_t = E_t \sum_{j=1}^{\infty} \delta^j \frac{U'(\tilde{Y}_{t+j})}{U'(Y_t)} \tilde{Y}_{t+j} \]

- asset price is the sum of all expected discounted future dividends (on the RHS, summing starts at \( t + 1 \))

- discounting is at the intertemporal marginal rate of substitution (IMRS) of the representative agent!
Interpreting the Exchange Equilibrium

Define the period $t$ to $t+1$ return for security $j$ as

$$1 + r_{jt+1} = \frac{p_{jt+1} + Y_{jt+1}}{p_{jt}}$$

Using equation (*),

$$1 = \delta E_t \left[ \frac{U'(\tilde{c}_{t+1})}{U'(c_t)} (1 + \tilde{r}_{jt+1}) \right]$$

Let $q^b_t$ denote the $t$-period price of a one-period riskless discount bond paying 1 unit of consumption at $t+1$ in every state.

$$q^b_t = \delta E_t \left[ \frac{U'(\tilde{c}_{t+1})}{U'(c_t)} \cdot 1 \right]$$

Since the riskfree rate is defined from $q^b_t(1 + r_{ft+1}) = 1$,

$$\frac{1}{1 + r_{ft+1}} = \delta E_t \left[ \frac{U'(\tilde{c}_{t+1})}{U'(c_t)} \right]$$

Under risk-neutrality, $U(c_t)$ is linear, $r_{ft+1}$ is constant. Link between discount factor and risk-free rate in a risk neutral world.
Interpreting the Exchange Equilibrium

\[ 1 = \delta E_t \left[ \frac{U'(\tilde{c}_{t+1})}{U'(c_t)} \right] \left( 1 + \tilde{r}_{jt+1} \right) \]

\[ 1 = \delta E_t \left[ \frac{U'(\tilde{c}_{t+1})}{U'(c_t)} \right] E_t[1 + \tilde{r}_{jt+1}] + \delta \text{cov}_t \left( \frac{U'(\tilde{c}_{t+1})}{U'(c_t)}, \tilde{r}_{jt+1} \right) \]

\[ = 1/(1 + r_{ft+1}) \]

(since \( \text{cov}(X, Y) = E[XY] - E[X]E[Y] \). Define \( E_t[1 + \tilde{r}_{jt+1}] = 1 + \bar{r}_{jt+1} \).)

\[ \frac{1 + \bar{r}_{jt+1}}{1 + r_{ft+1}} = 1 - \delta \text{cov}_t \left( \frac{U'(\tilde{c}_{t+1})}{U'(c_t)}, \tilde{r}_{jt+1} \right) \]

\[ \bar{r}_{jt+1} - r_{ft+1} = -\delta(1 + r_{ft+1})\text{cov}_t \left( \frac{U'(\tilde{c}_{t+1})}{U'(c_t)}, \tilde{r}_{jt+1} \right). \]
CAPM and CCAPM

CCAPM: \[ \tilde{r}_{jt+1} - r_{ft+1} = -\text{cov}_t \left( \frac{U'(\tilde{c}_{t+1})}{U'(c_t)}, \tilde{r}_{jt+1} \right) \delta(1 + r_{ft+1}) \]

CAPM: \[ \tilde{r}_{jt+1} - r_{ft+1} = \frac{\text{cov}(\tilde{r}_m, \tilde{r}_j)}{\text{var}(\tilde{r}_m)} (\overline{r}_{mt+1} - r_{ft+1}), \]

\[ = \beta_j \]

- CCAPM: asset \( j \) pays high on average, relative to the riskfree rate, if the covariance between \( U'(\tilde{c}_{t+1}) \) and the return on asset \( j \) is negative and large—i.e. consumption is low (= \( U'(\tilde{c}_{t+1}) \) is high) when the return is low. Such an asset will have low price \( p_t \), and high expected return.

- CAPM: asset \( j \) pays high on average if asset pays low when market pays low (i.e. asset is risky).

- CCAPM: Key to an asset’s value is its covariation with the marginal utility of consumption! Consumption-smoothing perspective.
Towards a CAPM equation in the CCAPM framework

Let $U(c_t) = ac_t - \frac{b}{2}c_t^2$, $a, b > 0$, $a - bc_t > 0$ for all $c_t$.

\[ \tilde{r}_{jt+1} - r_{ft+1} = -\delta(1 + r_{ft+1}) \text{cov}_t \left( \frac{a - b \tilde{c}_{t+1}}{a - bc_t}, \tilde{r}_{jt+1} \right) \]

\[ \tilde{r}_{jt+1} - r_{ft+1} = -\delta(1 + r_{ft+1}) \frac{-b}{a - bc_t} \text{cov}_t \left( \tilde{c}_{t+1}, \tilde{r}_{jt+1} \right) \]

\[ \tilde{r}_{jt+1} - r_{ft+1} = \frac{\delta b (1 + r_{ft+1})}{a - bc_t} \text{cov}_t \left( \tilde{c}_{t+1}, \tilde{r}_{jt+1} \right) \]

Asset $j$ has a high return on average if it pays low when consumption is low, i.e. when $\text{cov}_t \left( \tilde{c}_{t+1}, \tilde{r}_{jt+1} \right) > 0$. 
The Formal Consumption CAPM

\[ \bar{r}_{ct+1} - r_{ft+1} = \frac{\delta b (1 + r_{ft+1})}{a - bc_t} \text{cov}_t (\tilde{c}_{t+1}, \tilde{r}_{ct+1}) \]

“c” denotes portfolio most correlated with consumption

\[ \frac{\bar{r}_{jt+1} - r_{ft+1}}{\bar{r}_{ct+1} - r_{ft+1}} = \frac{\text{cov}_t (\tilde{c}_{t+1}, \tilde{r}_{jt+1}) / \text{var}_t (\tilde{c}_{t+1})}{\text{cov}_t (\tilde{c}_{t+1}, \tilde{r}_{ct+1}) / \text{var}_t (\tilde{c}_{t+1})} = \frac{\beta_{j,ct}}{\beta_{c,ct}} \]

\[ \bar{r}_{jt+1} - r_{ft+1} = \beta_{j,ct} (\bar{r}_{ct+1} - r_{ft+1}) \quad \text{if} \quad \beta_{c,ct} = 1 \]

Compare this to the CAPM equation:

\[ \bar{r}_{jt+1} - r_{ft+1} = \beta_{j,m} (\bar{r}_{mt+1} - r_{ft+1}) \]
Testing the Consumption CAPM: The Equity Premium Puzzle

<table>
<thead>
<tr>
<th></th>
<th>mean, %</th>
<th>s.d., %</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{r} )</td>
<td>6.98</td>
<td>16.54</td>
</tr>
<tr>
<td>( r_f )</td>
<td>0.80</td>
<td>5.67</td>
</tr>
<tr>
<td>( \bar{r} - r_f )</td>
<td>6.18</td>
<td>16.67</td>
</tr>
</tbody>
</table>


A reasonably parameterized CCAPM is unable to explain \( \bar{r} - r_f \) (=the equity premium), the difference in ex-post return on a diversified portfolio of U.S. stocks (S&P 500), and the return on one-year T-bills.
Equity premium, annual time series

Fig. 1. Realized equity risk premium per year, 1926–2000. Source: Ibbotson (2001).
Variation in the equity premium over time
The equity premium has varied considerably over time, as illustrated in Figures 1 and 2. Furthermore, the variation depends on the time horizon over which it is measured. There have even been periods when the equity premium has been negative.

Fig. 2. Equity risk premium over 20-year periods, 1926–2000. Source: Ibbotson (2001).
The annual return on the British stock market was 5.7% over the post-war period, an impressive 4.6% premium over the average bond return of 1.1% Similar statistical differentials are documented for France, Germany and Japan Table 2 illustrates the equity premium in the post-war period for these countries.

The dramatic investment implications of this differential rate of return can be seen in Table 3, which maps the capital appreciation of $1 invested in different assets from 1802 to 1997 and from 1926 to 2000.

As Table 3 illustrates, $1 invested in a diversified stock index yields an ending wealth of $558,945 versus a value of $276, in real terms, for $1 invested in a portfolio of T-bills for the period 1802-1997 The corresponding values for the 75-year period, 1926-2000, are $266.47 and $1.71 We assume that all payments to the underlying asset, such as dividend payments to stock and interest payments to bonds are reinvested and that there are no taxes paid.

This long-term perspective underscores the remarkable wealth building potential of the equity premium It should come as no surprise therefore, that the equity premium is of central importance in portfolio allocation decisions, estimates of the cost of capital and is front and center in the current debate about the advantages of investing Social Security funds in the stock market.

In Table 4 we report the premium for some interesting sub-periods: 1889-1933, when the USA was on a gold standard; 1934-2000, when it was off the gold standard;

### Table 2

<table>
<thead>
<tr>
<th>Country</th>
<th>% real return on a market index (mean)</th>
<th>% real return on a relatively riskless security (mean)</th>
<th>% equity premium (mean)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>5.7</td>
<td>1.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Japan</td>
<td>4.7</td>
<td>1.4</td>
<td>3.3</td>
</tr>
<tr>
<td>Germany</td>
<td>9.8</td>
<td>3.2</td>
<td>6.6</td>
</tr>
<tr>
<td>France</td>
<td>9.0</td>
<td>2.7</td>
<td>6.3</td>
</tr>
</tbody>
</table>

*Source: UK from Siegel (1998), the rest are from Campbell (2001).*
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The equity premium puzzle

\[ U(c) = \frac{c^{1-\gamma}}{1 - \gamma} \]

Assume \( x_{t+1} \equiv \frac{c_{t+1}}{c_t} \sim \text{iid lognormal}(1.0183, 0.0357^2) \), and so \( \log x_{t+1} \sim \text{iidN}(\mu_x, \sigma_x^2) \). Then,

\[
1.0183 = \exp(\mu_x + \frac{1}{2}\sigma_x^2)
\]

\[
0.0357^2 = \exp(2\mu_x + \sigma_x^2)[\exp(\sigma_x^2 - 1)]
\]

Solving, \( \mu_x = 0.01752, \sigma_x^2 = 0.00123 \).
The equity premium puzzle

Assume

\[ p_t = vY_t \]

The stock price at \( t \) is proportional to the dividend paid at \( t \).

Verify that it qualifies for a solution:

\[ vY_t = \delta E_t \left[ (v\tilde{Y}_{t+1} + \tilde{Y}_{t+1}) \frac{U'(\tilde{c}_{t+1})}{U'(c_t)} \right] \]

\[ v = \delta E_t \left[ (v + 1) \frac{\tilde{Y}_{t+1}}{Y_t} \right] \]

\[ = \tilde{x}_{t+1}: \text{Lucas tree} \]

\[ v = \frac{\delta E[\tilde{x}^{1-\gamma}]}{1 - E[\tilde{x}^{1-\gamma}]} \]

indeed a constant
The equity premium puzzle

\[ R_{t+1} = 1 + r_{t+1} = \frac{p_{t+1} + Y_{t+1}}{p_{t+1}} = \frac{v + 1}{v} \frac{Y_{t+1}}{Y_t} = \frac{v + 1}{v} x_{t+1} \]

\[ E_t \tilde{R}_{t+1} = \frac{v + 1}{v} E_t \tilde{x}_{t+1} = \frac{E[\tilde{x}]}{\delta E[\tilde{x}^{1-\gamma}]} \]

\[ R_{ft+1} = \frac{1}{q_t^b} = \left[ \delta E_t \frac{U'(%5\tilde{c}_{t+1})}{U'(c_t)} \right]^{-1} = \frac{1}{\delta} \frac{1}{E[\tilde{x}^{-\gamma}]} \]

\[ \frac{E_t \tilde{R}_{t+1}}{R_{ft+1}} = \frac{E[\tilde{x}] E[\tilde{x}^{-\gamma}]}{E[\tilde{x}^{1-\gamma}]} = \frac{\exp(\mu_x + 0.5\sigma_x^2) \exp(-\gamma \mu_x + 0.5\gamma^2 \sigma_x^2)}{\exp((1-\gamma)\mu_x + 0.5(1-\gamma)^2\sigma_x^2)} \]

\[ = \exp(\gamma \sigma_x^2) \]

\[ \log(E[R]) - \log(R_f) \approx \bar{r} - r_f = \gamma \sigma_x^2 \]
The equity premium puzzle

\[ \bar{r} - r_f = \gamma \sigma_x^2 \]

\[ \gamma = \frac{\bar{r} - r_f}{\sigma_x^2} = \frac{0.0698 - 0.008}{0.0357^2} \approx 50 \]

If a more realistic \( \gamma = 2 \) is assumed, \( \bar{r} - r_f \approx 0.2\% \).
Is $\gamma = 50$ realistic?

Assume current wealth 50,000, utility function $u(W) = \frac{W^{1-\gamma}}{1-\gamma}$ and a chance to play the gamble (0,1/2; 50000,1/2). What is the certainty equivalent (CE) of the gamble? (\(\Pi\) is the maximum willing to pay to avoid playing the gamble (−25000,1/2; 25000,1/2) with the current wealth of 75,000.)

<table>
<thead>
<tr>
<th>$\gamma$</th>
<th>CE</th>
<th>$\Pi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>25,000</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>20,711</td>
<td>4,289</td>
</tr>
<tr>
<td>3</td>
<td>13,246</td>
<td>11,754</td>
</tr>
<tr>
<td>5</td>
<td>8,566</td>
<td>16,434</td>
</tr>
<tr>
<td>10</td>
<td>3,991</td>
<td>21,009</td>
</tr>
<tr>
<td>20</td>
<td>1,858</td>
<td>23,142</td>
</tr>
<tr>
<td>30</td>
<td>1,209</td>
<td>23,791</td>
</tr>
<tr>
<td>50</td>
<td>712</td>
<td>24,288</td>
</tr>
</tbody>
</table>
The risk-free rate puzzle

Similarly, if $\gamma = 2$,

$$\delta = \frac{1}{R_{ft+1} E[\tilde{x} - \gamma]} = \frac{1}{1.008 \exp(-\gamma \mu_x + 0.5\gamma^2 \sigma_x^2)} \approx 1.02$$

The difficulty in explaining the low rate of return on the riskfree asset is called the risk-free rate puzzle.

$$R_{ft+1} = \frac{1}{\delta E[\tilde{x} - \gamma]} = \frac{1}{\delta \exp(-\gamma \mu_x + 0.5\gamma^2 \sigma_x^2)}$$

$$\log(R_{ft+1}) = -\log(\delta) + \gamma \mu_x - 0.5\gamma^2 \sigma_x^2$$

impatience term + consumption smoothing under certainty demand for precautionary savings

If $\gamma = 3$ and $\delta = 0.99$, $r_{ft+1} \approx 6\%$. 
Testing the Consumption CAPM: Hansen-Jagannathan Bounds

\[ 1 = E_t \left[ \frac{\delta U''(\tilde{c}_{t+1})}{U'(c_t)} \left( 1 + \tilde{r}_{j, t+1} \right) \right] \equiv \tilde{m}_{t+1} \]

\[ 1 = E_t \left[ \tilde{m}_{t+1} \tilde{R}_{t+1} \right] \]

Should hold unconditionally:

\[ 1 = E \left[ \tilde{m}_{t+1} \tilde{R}_{t+1} \right] \]

\( \tilde{m} \) is called the equilibrium pricing kernel, or the stochastic discount factor.
Hansen-Jagannathan bounds

\[ E[\tilde{m}\tilde{R}] = 1 \]

\[ E\left[ \tilde{m}(\tilde{R}_i - \tilde{R}_j) \right] = 0 \quad \equiv \tilde{R}_{i-j} \]

\[ E[\tilde{m}] E[\tilde{R}_{i-j}] + \text{cov}(\tilde{m}, \tilde{R}_{i-j}) = 0 \]

\[ \frac{E[\tilde{R}_{i-j}]}{\sigma_{R_{i-j}}} = -\rho(\tilde{m}, \tilde{R}_{i-j}) \frac{\sigma_m}{E[\tilde{m}]} \]

\[ \frac{|E[\tilde{R}_{i-j}]|}{\sigma_{R_{i-j}}} = |\rho(\tilde{m}, \tilde{R}_{i-j})| \frac{\sigma_m}{E[\tilde{m}]} \leq \frac{\sigma_m}{E[\tilde{m}]} \]

\[ \frac{\sigma_m}{E[\tilde{m}]} \geq \frac{|E(\tilde{R}_{i-j})|}{\sigma_{R_{i-j}}} \]

\[ \rho(\tilde{m}, \tilde{R}_{i-j}) \] is the correlation between the pricing kernel and \( \tilde{R}_{i-j} \).
Hansen-Jagannathan bounds

Set $i$ to $m$ (market) and $j$ to $f$ (riskfree asset) to obtain

$$\frac{\sigma_m}{E[\tilde{m}]} \geq \frac{|E(\tilde{r}_m - r_f)|}{\sigma_{r_m-r_f}} = \frac{0.062}{0.167} \approx 0.37$$

Assuming $\delta = 0.99$ and $\gamma = 2$

$$E[\tilde{m}] = \delta \tilde{x}^{-\gamma} = \delta \exp(-\gamma \mu_x + 0.5\gamma^2 \sigma_x^2) \approx 0.96$$

Therefore, the lowest value for $\sigma_m \approx 0.36.$

Using the chosen parameters, however, $\sigma_m = 0.002$, an order of magnitude lower!
Solutions?

- **Habit formation**—makes IMRS, the pricing kernel in the CCAPM, more volatile
- **Heterogeneity**—if markets are incomplete, income risk is persistent, and the variance of consumption growth is countercyclical (higher in recessions than in normal times), the model-implied equity premium will be higher

—“...the risk premium is highest in a recession since equities are a poor hedge against the potential loss of employment...even though per capita consumption growth is poorly correlated with stocks returns, investors require a **hefty premium to hold stocks over short-term bonds** because stocks perform poorly **in recessions**, when an investor is **more likely to be laid off.**” Mehra & Prescott (2003).
- **Limited stock-market participation**—the relevant stochastic discount factor is IMRS of stockholders whose consumption growth is more volatile