Asset Pricing in Intertemporal Consumption Models

October 5, 2011

Asset Pricing Applications

- Lucas-tree model
- General equilibrium asset pricing
- Equity premium puzzle
- Risk-free rate puzzle
- Alternative preference specifications
  - Recursive utility (Epstein-Zin)
  - Habit persistence
  - Hyperbolic discounting
- Risk sharing
- (Constructing the representative consumer)

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- ❑ **Lucas-tree model**
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- ❑ Risk sharing
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An Equilibrium Asset Pricing Model

- ❑ **Modify interpretation of intertemporal model**

$$\max_{\{c_t, a_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t u(c_t) \text{ subject to } c_t + s_t a_t = d_t a_{t-1} + s_t a_{t-1}, \quad t = 0, 1, 2, \ldots$$

a_t : end-of-period-t holdings of shares of an asset
s_t : period-t price of a share
d_t : period-t per-share dividend

AN EQUILIBRIUM ASSET PRICING MODEL

- **Modify interpretation of intertemporal model**

$$\max_{\{c_t, a_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t u(c_t) \text{ subject to } c_t + s_t a_t = d_t a_{t-1} + s_t a_{t-1}, \quad t = 0,1,2,...$$

a_t : end-of-period-*t* holdings of shares of an asset
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- **Equivalently express budget constraint as**

$$c_t + \underbrace{s_t(a_t - a_{t-1})}_{} = d_t a_{t-1}, \quad t = 0,1,2,...$$

change in share holdings, i.e., quantity of savings

- **"Supply-side" of financial markets**
  - **a_t = 1 ∀ *t* – an equilibrium outcome**
  - **Do not/cannot impose when solving consumer problem!**

AN EQUILIBRIUM ASSET PRICING MODEL

- **FOCs yield asset pricing equation**

$$s_t = E_t \left\{ \underbrace{\frac{\beta \lambda_{t+1}}{\lambda_t}} (d_{t+1} + s_{t+1}) \right\}, \quad t = 0,1,2,...$$

Pricing kernel
aka stochastic discount factor (SDF)

↓ **Can express in terms of marginal utilities…but don't have to**

$$s_t = E_t \left\{ \frac{\beta u'(c_{t+1})}{u'(c_t)} (d_{t+1} + s_{t+1}) \right\}, \quad t = 0,1,2,...$$

Period-*t* asset price = **SDF** x **Future return**

Two components:
1. **Future price of stock**
2. **Future dividend payment**

An Equilibrium Asset Pricing Model

- **Basic asset pricing equation**

$$s_t = E_t\left\{\frac{\beta\lambda_{t+1}}{\lambda_t}\left(d_{t+1}+s_{t+1}\right)\right\}, \quad t=0,1,2,\ldots$$

↓ **Recursively substitute forward**

= 0

$$s_t = E_t\left\{\sum_{\tau=t+1}^{\infty}\frac{\beta^{\tau-t}\lambda_\tau}{\lambda_t}d_\tau\right\}+\lim_{\tau\to\infty}E_t\frac{\beta^{\tau-t}\lambda_\tau}{\lambda_t}s_\tau$$

- **Impose a TVC**
- **Similar intuition as** $\lim_{t\to\infty}\beta^t u'(c_t^*)a_t^*=0$
  - **Value of terminal asset holdings (in present-value utils) must → 0**
  - **There: had price of asset = 1, so needed terminal condition on quantity**

An Equilibrium Asset Pricing Model

- **Basic asset pricing equation**

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- **Impose a TVC**
  - **Rules out "asset price bubbles"**
- **The basic form of any asset pricing condition**

EQUILIBRIUM ASSET PRICING

- **Basic asset pricing equation**

$$s_t = E_t\left\{\sum_{\tau=t+1}^{\infty}\frac{\beta^{\tau-t}\lambda_\tau}{\lambda_t}d_\tau\right\} \quad \textbf{OR} \quad s_t = E_t\left\{\frac{\beta\lambda_{t+1}}{\lambda_t}\left(d_{t+1}+s_{t+1}\right)\right\}, \quad t = 0,1,2,\ldots$$

with TVC imposed

- **Lucas (1978) model**
  - **$\{d_\tau\}_{\tau=t,t+1,\ldots}$ follows Markov process**
  - **"Supply-side" of financial markets is $a_\tau = 1$ $\forall\tau$**
  - **Suppose representative consumer**
- **Implementing representative consumer**
  - **An infinity of consumers, each indexed by a point on the unit interval [0,1]**
  - **Each individual is identical in preferences and endowments**
  - **Implies aggregate consumption demand and asset demand**

Aggregate consumption demand = One individual's consumption demand x Total measure of individuals

Aggregate savings demand = One individual's savings demand x Total measure of individuals

Lucas (1978)

EQUILIBRIUM ASSET PRICING

- **Basic asset pricing equation**

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with TVC imposed

- **Lucas (1978) model**
  - **$\{d_\tau\}_{\tau=t,t+1,\ldots}$ follows Markov process**
  - **"Supply-side" of financial markets is $a_\tau = 1$ $\forall\tau$**
  - **Solution is a consumption and asset price sequence $\{c_\tau^*, a_\tau^*\}_{\tau=t,t+1,t+2,\ldots}$ that satisfies**
    - **Sequence of stochastic pricing conditions**

$$s_\tau^* = E_t\left\{\sum_{\tau=t+1}^{\infty}\frac{\beta^{\tau-t}u'(c_\tau^*)}{u'(c_t^*)}d_\tau\right\}$$

in which TVC ("no-bubbles") is already imposed

    - **Sequence of budget constraints with asset-market clearing condition $a_\tau = 1$ imposed**

$$c_\tau^* = d_\tau, \quad \tau = t, t+1, t+2, \ldots$$

taking as given exogenous law of motion for d_τ

EQUILIBRIUM ASSET PRICING

- **What if N assets?**

$$\max_{\{c_t,a_t\}_{t=0}^{\infty}} E_0\sum_{t=0}^{\infty}\beta^t u(c_t) \quad \textbf{subject to} \quad c_t + \sum_{j=1}^{N}s_t^j a_t^j = \sum_{j=1}^{N}d_t^j a_{t-1}^j + \sum_{j=1}^{N}s_t^j a_{t-1}^j, \quad t=0,1,2,\ldots$$

  - **Not necessarily Arrow-Debreu assets**
  - ***N* not necessarily equal to the number of exogenous states of nature**
  - **a^j_t : end-of-period-*t* holdings of shares of asset *j***
  - **s^j_t : period-*t* price of a share of asset *j***
  - **d^j_t : period-*t* per-share dividend from asset *j***

- **FOCs yield *N* asset pricing equations**

$$s_t^j = E_t\left\{\frac{\beta\lambda_{t+1}}{\lambda_t}\left(d_{t+1}^j + s_{t+1}^j\right)\right\}, \quad j=1,2,\ldots,N, t=0,1,2,\ldots$$

  - **Each has identical SDF**

Lucas (1978)

Equilibrium Asset Pricing

$$E_t\left\{\underbrace{\frac{\beta\lambda_{t+1}}{\lambda_t}}_{\text{SDF}}\underbrace{\left(\frac{d^j_{t+1}+s^j_{t+1}}{s^j_t}\right)}_{\text{Gross return on one unit of } a^j}\right\}=1$$

Demand-side pricing condition for asset *j*

- **Finance applications sometimes/often suppose SDF follows exogenous law of motion**
  - **May be useful for making progress on understanding asset pricing if we have the wrong model of (intertemporal) consumption**

Lucas (1978)

Equilibrium Asset Pricing

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- **Consumption-based asset pricing**

$$E_t\left\{\underbrace{\frac{\beta u'(c_{t+1})}{u'(c_t)}}_{\text{Growth of marginal utility}}\left(\frac{d^j_{t+1}+s^j_{t+1}}{s^j_t}\right)\right\}=1 \quad \longleftrightarrow \quad E_t\left\{\beta u'(c_{t+1})\left(\frac{d^j_{t+1}+s^j_{t+1}}{s^j_t}\right)\right\}=u'(c_t)$$

Interpretation: on average, in future states in which marginal utility is low, asset *j*'s return must be high in order to be induced to hold it

ASSET PRICING APPLICATIONS

- Lucas-tree model
- General equilibrium asset pricing
- **Equity premium puzzle**
- **Risk-free rate puzzle**
- Alternative preference specifications
  - Recursive utility (Epstein-Zin)
  - Habit persistence Recursive utility (Epstein-Zin)
  - Hyperbolic discounting
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EQUILIBRIUM ASSET PRICING

- **No-arbitrage conditions**
  - **For any assets a^i, a^k**

$$E_t\left\{\underbrace{\frac{\beta u'(c_{t+1})}{u'(c_t)}}_{\text{Growth of marginal utility}}\underbrace{\left(\underbrace{\frac{d^i_{t+1}+s^i_{t+1}}{s^i_t}}_{\text{Gross return on one unit of } a^i}-\underbrace{\frac{d^k_{t+1}+s^k_{t+1}}{s^k_t}}_{\text{Gross return on one unit of } a^k}\right)}_{\text{Return premium of asset } i \text{ over asset } k}\right\}=0$$

  - **Provides foundation for various empirical tests of "market efficiency"…**
  - **…or simply the underlying structure of the model**
- **Mehra and Prescott (1985 *JME*)**
  - **Test how well model does in jointly explaining returns on aggregate equity and risk-free bonds**
  - **Representative agent**
  - **Only two assets: a Lucas tree (stock) and risk-free bond**
  - **Main result: equity premium puzzle**

Equity Premium Puzzle

$$\max_{\{c_t,a_t,b_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t u(c_t) \quad \textbf{subject to} \quad c_t + s_t a_t + R_t^f b_t = d_t a_{t-1} + s_t a_{t-1} + b_{t-1}, \quad t = 0,1,2,...$$

a_t : end-of-period-t holdings of shares of an asset – interpret as stock
s_t : period-t price of a share
d_t : period-t per-share dividend
b_t : end-of-period-t holdings of risk-free bond – interpret as short-term Tbill
R^f_t: period-t price of risk-free bond that matures in period t+1

- **Asset-pricing conditions**

$$s_t = E_t\left\{\frac{\beta u'(c_{t+1})}{u'(c_t)}(d_{t+1}+s_{t+1})\right\} \qquad R_t^f = E_t\left\{\frac{\beta u'(c_{t+1})}{u'(c_t)}\right\}$$

$$\updownarrow \qquad\qquad \updownarrow$$

$$1 = E_t\left\{\frac{\beta u'(c_{t+1})}{u'(c_t)}\underbrace{\left(\frac{d_{t+1}+s_{t+1}}{s_t}\right)}_{\equiv 1/R^s_{t+1}}\right\} \quad \underset{\text{No arbitrage}}{=} \quad 1 = E_t\left\{\frac{\beta u'(c_{t+1})}{u'(c_t)}\frac{1}{R_t^f}\right\}$$

Equity Premium Puzzle

- **Can standard intertemporal consumption model reasonably jointly explain risk-free returns and risky (stock) returns?**

$$\textbf{(1)} \quad E_t\left\{\frac{\beta u'(c_{t+1})}{u'(c_t)}\frac{1}{R_t^f}\right\} = 1 \qquad \textbf{(2)} \quad E_t\left\{\frac{\beta u'(c_{t+1})}{u'(c_t)}\underbrace{\left(\frac{1}{R^s_{t+1}} - \frac{1}{R_t^f}\right)}_{\text{Equity premium}}\right\} = 0$$

- **Mehra and Prescott (1985 *JME*)**
  - **Originally posed question**
  - **Answered in the negative!**

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- **EQUITY PREMIUM PUZZLE**
  - **An ongoing central issue in finance and macroeconomics**
  - **Not a qualitative shortcoming of basic model**
  - **A (spectacular) quantitative shortcoming of basic model**
- **Good overviews/reviews**
  - **Kocherlakota (1996 *JEL*)**
  - **Mehra and Prescott (2003, *Handbook of Economics and Finance*)**
  - **Cochrane, Chapter 21**

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- **Start with (2)**

$$\longrightarrow \qquad E_t\left(\frac{1}{R_{t+1}^s}\right)=\frac{1}{R_t^f}-\frac{Cov_t\left(u'(c_{t+1})/u'(c_t),1/R_{t+1}^s\right)}{E_t[u'(c_{t+1})/u'(c_t)]}$$

- **Identify $1/R^s_{t+1}$ as real return on broad stock index (i.e., S&P500)**
- **Identify $1/R^f_t$ as real return on (nominally) risk-free short T-bills**
- **Expected return on equity = risk-free return + premium for bearing risk**
- **Premium depends on covariance of equity return with marginal utility**
- **Recall interpretation: on average, in future states in which marginal utility is low, asset *j*'s return must be high in order to be induced to hold it**

Equity Premium Puzzle

$$E_t\left(\frac{1}{R^s_{t+1}}\right)=\frac{1}{R^f_t}-\frac{Cov_t\left(u'(c_{t+1})/u'(c_t),1/R^s_{t+1}\right)}{E_t[u'(c_{t+1})/u'(c_t)]}$$

- **Expected return on equity = risk-free return + premium for bearing risk**
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↕

- **Assets that co-vary positively with consumption over time (negatively with future MU of consumption) command a high premium because their returns are "destabilizing"**
  - **i.e., push individual away from consumption smoothing across future risky states**
- **Test using standard CRRA** $u(c_t)=\frac{c_t^{1-\sigma}-1}{1-\sigma}$

Equity Premium Puzzle

$$E_t\left(\frac{1}{R^s_{t+1}}\right)=\frac{1}{R^f_t}-\frac{Cov_t\left((c_{t+1}/c_t)^{-\sigma},1/R^s_{t+1}\right)}{E_t(c_{t+1}/c_t)^{-\sigma}}$$

- **Can test with variety of aggregate stock returns (inclusive of dividends)**
- **Construct real risk-free rate from nominal short interest rates and inflation**
- **Mehra and Prescott (1985) – use data from 1889-1978**
- **Can apply various sophisticated econometric tools (GMM, Bayesian, etc)**
- **Sample means convey basic problem – approximate with unconditional *E*(.)**

Equity Premium Puzzle

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- Can test with variety of aggregate stock returns (inclusive of dividends)
- Construct real risk-free rate from nominal short interest rates and inflation
- Mehra and Prescott (1985) – use data from 1889-1978
- Can apply various sophisticated econometric tools (GMM, Bayesian, etc)
- Sample means convey basic problem – approximate with unconditional *E*(.)
- Sample statistics, 1889-1978 (annual data)
  - mean($1/R^f$) = 1.01
  - mean($1/R^s$)= 1.07
  - mean(c_{t+1}/c_t)= 1.018
  - SD(c_{t+1}/c_t) = 0.036
  - SD(R^s_t) = 0.0274
  - Cov(c_{t+1}/c_t, R^s_t) = 0.00219

Explaining 6 percent equity premium with growth rates of aggregate consumption requires a stand on RRA σ…

…and then computing Cov(.) based on it

Equity Premium Puzzle

$$E\left(\frac{1}{R^s_{t+1}}\right)=\frac{1}{R^f_t}-\frac{Cov\left((c_{t+1}/c_t)^{-\sigma},1/R^s_{t+1}\right)}{E(c_{t+1}/c_t)^{-\sigma}}$$

- What are "reasonable" values of RRA?
- Business-cycle models require $\sigma \approx 1$ (Econ 701)
- Microeconomic evidence higher(?) risk aversion
- Hall (1988) evidence indicates IES ≈ 0.1
  - If CRRA → $\sigma \approx 10$
  - (Though Hall disavows that he is measuring risk aversion – Kocherlakota says argument is deeply flawed (1990, *JFin* p. 175))
- Mehra and Prescott assert σ = 10 as extreme upper bound on risk aversion

Seminal Finance Application

Equity Premium Puzzle

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- **Mehra and Prescott assert σ = 10 as extreme upper bound on risk aversion**

- **σ = 10**
  - **Standard model explains ≈ 0.3 percent of the 6 percent equity premium**
  - **An order of magnitude off! Even though σ = 10 already "too high"(?)**

- **Explaining equity premium with standard model requires $\sigma \approx 50$!**

Seminal Finance Application

Equity Premium Puzzle

(1) $$\beta E\left\{\left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}\right\}=\frac{1}{1/R^f_t}$$ **(2)** $$E\left(\frac{1}{R^s_{t+1}}\right)=\frac{1}{R^f_t}-\frac{Cov\left((c_{t+1}/c_t)^{-\sigma},1/R^s_{t+1}\right)}{E(c_{t+1}/c_t)^{-\sigma}}$$

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- **Explaining equity premium with standard model requires $\sigma \approx 50$!**

- **If accept $\sigma \approx 50$**
  - **Requires accepting virtually zero IES (not inconsistent with Hall 1988…)…**
  - **…and generates another anomaly**

- **If prior is $\beta \approx 0.98$-0.99, (1) implies $1/R^f$ = …?**

Equity Premium and Risk-Free Rate Puzzles

(1) $\beta E\left\{\left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}\right\} = \frac{1}{1/R_t^f}$ (2) $E\left(\frac{1}{R_{t+1}^s}\right) = \frac{1}{R_t^f} - \frac{Cov\left((c_{t+1}/c_t)^{-\sigma}, 1/R_{t+1}^s\right)}{E(c_{t+1}/c_t)^{-\sigma}}$

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- **If accept $\sigma \approx 50$**
  - **Requires accepting virtually zero IES (not inconsistent with Hall 1988…)…**
  - **…and generates another anomaly**
- **If prior is $\beta \approx$ 0.98-0.99, (1) implies $1/R^f \approx 1.1$**
  - **10 percent higher than empirical risk-free rate!**
- **(Extremely) high σ to fix equity premium puzzle causes risk-free rate puzzle!**
  - **Which can be offset by $\beta \approx$ 0.6…extreme impatience! "Hyperbolic?"**

Equity Premium and Risk-Free Rate Puzzles

(1) $\beta E\left\{\left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}\right\} = \frac{1}{1/R_t^f}$ (2) $E\left(\frac{1}{R_{t+1}^s}\right) = \frac{1}{R_t^f} - \frac{Cov\left((c_{t+1}/c_t)^{-\sigma}, 1/R_{t+1}^s\right)}{E(c_{t+1}/c_t)^{-\sigma}}$

- **With CRRA preferences, resolving both puzzles requires adopting view that consumers are**
  - **EXTREMELY risk averse**
  - **EXTREMELY impatient**

  } **CRRA fundamentally entangles risk attitudes and intertemporal attitudes**
- **Many assumptions underlying basic model**
  - **No transactions costs in financial markets**
  - **Everyone participates in all financial markets**
    - **i.e., no "limited participation"**
  - **A representative agent exists**
    - **i.e., can ignore heterogeneity in aggregating Euler equations**
    - **(recalls Attanasio criticism of Hall (1978))**
  - **Etc…**
- **First (most natural?) line of attack – modify $u(.)$ to disentangle IES and RRA**