# Homework 2

Tate Mason

ECON - 8050

## Problem 1: Costs of Business Cycle

Let utility be given by:

$$E_{-1}\sum_{t=0}^{\infty}\beta^t U(c_t)$$

where the utility function is CRRA:

$$U(c_t) = \frac{c_t^{1-\gamma}}{1-\gamma}$$

The consumption process is

$$c_t = c_{t-1}^{\alpha}\varepsilon_t \exp(\mu)$$

where

$$\mu = \frac{-\sigma_\varepsilon^2(1-\alpha)}{2(1-\alpha^2)}, \quad \log\varepsilon_t \sim N(0,\sigma_\varepsilon^2) \text{ and i.i.d.}$$

Thus, the log of consumption follows an AR(1) process:

$$\log c_t = \mu + \alpha \log c_{t-1} + \log \varepsilon_t$$

### Part A

Find the unconditional mean of $c_t$, $E(c_t)$. (Hint: recall the properties of the lognormal distribution).

### Part B

Define lifetime utility before any uncertainty is realized as:

$$V_0 = E_{-1}\sum_{t=0}^{\infty}\beta^t U(c_t)$$

Assume $c_0$ is drawn from the invariant (unconditional) distribution of $c$. Now define:

$$V(\lambda) = E_{-1}\sum_{t=0}^{\infty}\beta^t U[c_t(1+\lambda)]$$

This is lifetime utility when every period consumption is increased by $(1+\lambda)$. Express $V(\lambda)$ as a function of $\mu, \sigma_\varepsilon^2, \alpha, \gamma, \beta$.

### Part C

Denote $V_0$ as the lifetime utility when $c_t$ is deterministic and equal to its unconditional mean found in part A). Find the compensation $\lambda$ such that $V(\lambda) = V_0$. Find how much compensation the consumer has to be given in order to be indifferent between the stochastic and deterministic cases, Provide economic intuition.

## Part D

Denote the interest rate as $r$. Find consumption $c_t$.

# Problem 2: Non-Expected Utility Framework

This problem follows the Kreps and Porteus (1978), Epstein and Zin (1991), and Weil (1990) frameworks.

Let remaining lifetime utility at time $t$, once $c_t$ is known, be given by $v_t$, satisfying:

$$v_t = \left[(1-\beta)c_t^\rho + \beta(E_t v_{t+1}^\alpha)^{\frac{\rho}{\alpha}}\right]^{\frac{1}{\rho}} \tag{1}$$

where $1-\alpha$ represents risk aversion and $1-\rho$ represents the inverse of the intertemporal elasticity of substitution. In standard expected utility, $\alpha = \rho$.

Denote pre-realization lifetime utility at time $t$ as $U_t$, where:

$$U_t = (E_t v_t^\alpha)^{\frac{1}{\alpha}}$$

## Part A

Prove that multiplying $c_t$ by $\lambda$ for all $t = 0, 1, \ldots, \infty$ is equivalent to multiplying $v_t$ by $\lambda$. (Hint: start by assuming this holds, substitute into equation (1), and show $v_t$ scales linearly.)

## Part B

Suppose for all $t$, we replace $c_t$ with a deterministic constant $\bar{c} = E[c_t]$. Compare welfare in this case with uncertain $c_t$. Specifically, find $\eta$ such that multiplying $c_t$ by $(1+\eta)$ makes ex-ante welfare $U_0$ equal to that in the deterministic case. Express $\eta$ in terms of $U_0$ and $\bar{c}$.

## Part C

Suppose consumption follows one of two sequences: with probability $\frac{1}{2}$, $c_t = c_l$ for all $t$, and with probability $\frac{1}{2}$, $c_t = c_h$ for all $t$. The sequence is revealed at $t = 0$. Find $\eta$ and analyze its dependence on $\rho$ and $\alpha$.

## Part D

Now assume $c_t$ is i.i.d., where each period $c_t = c_l$ with probability $\frac{1}{2}$ and $c_h$ with probability $\frac{1}{2}$.

1. Derive an implicit equation for $U_0$.
2. Analyze whether $\eta$ depends on $\alpha$ and $\rho$.

## Part E

Solve for $U_0$ numerically using Matlab with given parameters: $\beta = 0.95$, $c_l = e^{0.98}$, $c_h = e^{1.02}$. Compute $\eta$ for:

- $\alpha = 1, 0.5, -1$
- $\rho = 1, 0.5, -1$

Report results in a table and provide economic intuition. (Hint: Use an iterative approach to solve $U_0 = f(U_0)$ until convergence with tolerance $10^{-8}$.)

# 1 Solution 1

## (A)

If $c_t \sim N(m, v)$ for some mean $m$ and variance $v$, $\log c_t$ has a log normal distribution such that $\mathbb{E}[c_t] = \exp[m + \frac{v}{2}]$. Due to $c_t$ exhibiting an AR(1) process, we can say that $m = \mu + \alpha m + 0 \to m(1-\alpha) = \mu \to m = \frac{\mu}{1-\alpha}$. The unconditional variance can be found by the following $v = \alpha^2 v + \sigma_\epsilon^2 \to v = \frac{\sigma_\epsilon^2}{(1-\alpha^2)}$. Thus, $\mathbb{E}[c_t] = \exp[\frac{\mu}{1-\alpha} + \frac{\sigma_\epsilon^2}{2(1-\alpha^2)}]$ Subbing in the given $\mu$, $\exp[-\frac{\sigma_\epsilon^2 \mu}{2(1-\alpha^2)(1-\alpha)} + \frac{\sigma_\epsilon^2}{2(1-\alpha^2)}] \to \exp(0) = 1 = \mathbb{E}[c_t]$

## (B)

$$V_0 = \mathbb{E}_{-1} \sum_{t=0}^{\infty} \beta^t U(c_t)$$
$$V(\lambda) = \mathbb{E}_{-1} \sum_{t=0}^{\infty} \beta^t U(c_t(1+\lambda))$$
$$U(c_t(1+\lambda)) = (1+\lambda)^{1-\gamma} \frac{c_t^{1-\gamma}}{1-\gamma}$$
$$V(\lambda) = (1+\lambda)^{1-\gamma} \mathbb{E}_{-1} \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\gamma}}{1-\gamma} = (1+\lambda)^{1-\gamma} V_0$$

Now, we apply the same distribution as in (A) to $c_t^{1-\gamma}$.

$$\mathbb{E}[c_t^{1-\gamma}] = \exp[(1-\gamma)m + \frac{(1-\gamma)v}{2}]$$
$$\mathbb{E}[c_t^{1-\gamma}] = \exp[\frac{(1-\gamma)\mu}{1-\alpha} + \frac{(1-\gamma)^2 \sigma_\epsilon^2}{2(1-\alpha^2)}]$$
$$\therefore \ V_0 = \frac{1}{1-\gamma} \sum_{t=0}^{\infty} \beta^t \mathbb{E}[c_t^{1-\gamma}]$$
$$= \frac{1}{1-\gamma} \frac{1}{1-\beta} \exp[\frac{(1-\gamma)\mu}{1-\alpha} + \frac{(1-\gamma)^2 \sigma_\epsilon^2}{2(1-\alpha^2)}]$$
$$V(\lambda) = (1+\lambda)^{1-\gamma} \frac{1}{1-\gamma} \frac{1}{1-\beta} \exp[\frac{(1-\gamma)\mu}{1-\alpha} + \frac{(1-\gamma)\sigma_\epsilon^2}{2(1-\alpha^2)}]$$

## (C)

$$V_0 = \sum_{t=0}^{\infty} \beta^t U(1) = \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\gamma} = \frac{1}{(1-\beta)(1-\gamma)}$$

Indifference implies that $V_0 = V(\lambda)$. Therefore:

$$
\begin{aligned}
(1+\lambda)^{1-\gamma} \exp[\frac{(1-\gamma)\mu}{1-\alpha} + \frac{(1-\gamma)\sigma_\epsilon^2}{2(1-\alpha^2)}] = 1 \\
\Rightarrow (1-\gamma)\log(1+\gamma) + \frac{(1-\gamma)\sigma_\epsilon^2}{(1-\alpha)} + \frac{(1-\gamma)^2\sigma_\epsilon^2}{2(1-\alpha^2)} = 0 \\
\log(1+\lambda) = -\frac{\mu}{1-\alpha} + \frac{(1-\gamma)\sigma_\epsilon^2}{2(1-\alpha^2)} \\
1+\lambda = \exp[-\frac{\mu}{1-\alpha} + \frac{(1-\gamma)\sigma_\epsilon^2}{2(1-\alpha^2)}] \\
\lambda = \exp[-\frac{\mu}{1-\alpha} + \frac{(1-\gamma)\sigma_\epsilon^2}{2(1-\alpha^2)}] - 1 \\
\lambda = \exp[\frac{\sigma_\epsilon^2}{2(1-\alpha^2)} - \frac{(1-\gamma)\sigma_\epsilon^2}{2(1-\alpha^2)}] - 1 \\
\lambda = \exp[\frac{\sigma_\epsilon^2}{2(1-\alpha^2)}(1-1+\gamma)] - 1 \\
\lambda = \exp[\frac{\gamma\sigma_\epsilon^2}{2(1-\alpha^2)}] - 1
\end{aligned}
$$

### (D)

$$
\begin{aligned}
c_t^{-\gamma} = \beta(1+r)\mathbb{E}_t(c_{t+1}^{-\gamma}) \\
1 = \beta(1+r)\mathbb{E}_t(\frac{c_t^\alpha \epsilon_{t+1}\exp[\mu]}{c_{t-1}\epsilon_t \exp[\mu]})^{-\gamma} \\
\beta(1+r)\mathbb{E}_t(\alpha \log\frac{c_{t+1}}{c_t} + \log(\frac{\epsilon_{t+1}}{\epsilon_t}) + 1) = 1 \\
\beta(1+r)\mathbb{E}_t(\alpha\Delta\log c_{t+1} + 1) \text{ s.t. } \Delta\log c_{t+1} \sim N(\mathbb{E}_t\Delta\log c_{t+1}, v_t\Delta\log c_{t+1}) \\
\mathbb{E}_t(-\gamma\alpha\Delta\log c_{t+1} + 1) = (-\gamma\alpha\Delta\log c_{t+1} + \frac{1}{2}(\gamma\alpha)^2 v_t\Delta\log c_{t+1}) \\
\mathbb{E}_t\Delta\log c_{t+1} = \frac{\log\beta(1+r)}{\gamma\alpha} + \frac{1}{2}\gamma\alpha v_t\Delta\log c_{t+1}
\end{aligned}
$$

## Solution 2

### (A)

*Proof.* $v_t = [(1-\beta)(\lambda c_t)^\rho + \beta(\mathbb{E}[\lambda v_{t+1}]^\alpha)^{\frac{\rho}{\alpha}}]^{\frac{1}{\rho}}$ This allows us to move the $\lambda$ term out such that $v_t = [\lambda^\rho(1-\beta)(c_t^\rho)+\lambda^\rho\beta(\mathbb{E}[v_t]^\alpha)^{\frac{\rho}{\alpha}}]^{\frac{1}{\rho}}$. Finally, we can show that utility is linearly scaled by lambda such that $v_t = \lambda[(1-\beta)c_t^\rho + \beta(\mathbb{E}c_t^\alpha)^{\frac{\rho}{\alpha}}]^{\frac{1}{\rho}}$. □

### (B)

In the deterministic case, $v_t = v_{t+1} = U_0^d$. This allows us to write the uncertain case as $U_0^c(1+\eta) = U_0 \Rightarrow \eta\frac{U_0^d}{U_0^c} - 1\eta = \frac{\bar{c}}{U_0^c}^{\frac{1}{\rho}} - 1$.

### (C)