ASSIGNMENT II

Vision: This project teaches you to solve for the *stationary equilibrium* and *transition path* in a heterogeneous agent model and analyze the economic results.

- **Problem:** The problem consists of
  1. A number of questions (page 2)
  2. A model (page 3-4)
- **Code:** The problem is designed to be solved with the *GEModelTools* package.
- **Structure:** Your project should consist of
  1. A single self-contained pdf-file with all results
  2. A single Jupyter notebook showing how the results are produced
  3. Well-documented *.py* files
- **Hand-in:** Upload a single zip-file on Absalon (and nothing else)
- **Deadline:** 24th of November 2023
- **Exam:** Your Assignment II will be a part of your exam portfolio.
  You can incorporate feedback before handing in the final version.

HANC with a Welfare State

a) **Find the stationary equilibrium without a government** ($G_t = L_t^G = \chi_t = 0$)**.** *Code is provided as starting point.*

b) **Find optimal welfare policies I.** Choose G_t and L_t^G to maximize expected discounted utility in the stationary equilibrium. Keep $\chi_t = 0$.

c) **Find optimal welfare policies II.** Repeat b) allowing for $\chi_t > 0$.

d) **Increased TFP.** Repeat question c) with $\Gamma^Y = 1.1$. Comment on the differences.

e) **Transition path**. Compute the transition path from the stationary equilibrium in c) to the one in d). Argue for you choice of policies path of G_t, L_t^G and χ_t.

1. Model

Households. The model has a continuum of infinitely lived households indexed by $i \in [0,1]$. Households are *ex ante* homogeneous. Households choose consumption and how much labor to supply. Savings is in terms of capital, which is rented out to firms at the rental rate, r_t^K. There are no possibilities to borrow. Households are *ex post* heterogeneous in terms of their stochastic labor productivity, z_{it}, and their (end-of-period) savings, a_{it-1}. The distribution of households over idiosyncratic states is denoted $\underline{\boldsymbol{D}}_t$ before shocks are realized and $\boldsymbol{D}_t$ afterwards. The real wage is w_t, and real-profits are Π_t. The government imposes a proportional tax rate, τ_t, and provides real lump-sum transfers is χ_t and a flow of services S_t. Households choose consumption, c_{it} and labor supply, ℓ_{it}.

The household problem is

$$
\begin{aligned}
v_t(z_{it}, a_{it-1}) &= \max_{c_t} \frac{c_{it}^{1-\sigma}}{1-\sigma} + \frac{S_t^{1-\omega}}{1-\omega} - \varphi \frac{\ell_{it}^{1+\nu}}{1+\nu} + \beta \mathbb{E}_t \left[v_{t+1}(z_{it+1}, a_{it}) \right] \qquad (1) \\
\text{s.t. } a_{it} + c_{it} &= (1+r_t)a_{it-1} + (1-\tau_t) w_t z_{it} + \chi_t + \Pi_t \\
\log z_{it+1} &= \rho_s \log z_{it} + \psi_{it+1}, \quad \psi_{it+1} \sim \mathcal{N}(\mu_\psi, \sigma_\psi), \ \mathbb{E}[z_{it}] = 1 \\
a_{it} &\geq 0.
\end{aligned}
$$

where $r_t \equiv r_t^K - \delta$.

The aggregate quantities of central interest are

$$C_t^{hh} = \int c_{it} d\boldsymbol{D}_t \qquad (2)$$

$$L_t^{hh} = \int \ell_{it} z_{it} d\boldsymbol{D}_t \qquad (3)$$

$$A_t^{hh} = \int a_{it} d\boldsymbol{D}_t \qquad (4)$$

From here on the sub-script i is left out if not strictly necessary.

Firms. A representative firm rents capital, K_{t-1}, and hires labor L_t^Y to produce goods, with the production function

$$Y_t = \Gamma_t K_{t-1}^{\alpha} (L_t^Y)^{1-\alpha} \qquad (5)$$

where Γ_t is technology and α is the Cobb-Douglas weight parameter on capital. Capital depreciates with the rate $\delta \in (0,1)$. The real rental price of capital is r_t^K and the real wage is w_t. Profits are $\Pi_t = Y_t - w_t L_t - r_t^K K_{t-1}$. The households own the representative firm in equal shares.

The law-of-motion for capital is $K_t = (1-\delta)K_{t-1} + I_t$.

Government.

The government purchases goods, G_t, and hire labor L_t^G, to produce government services according to

$$S_t = \min\{G_t, \Gamma^G L_t^G\} \tag{6}$$

The government runs a balanced budget each period such that

$$G_t + w_t L_t^G + \chi_t = \int \tau_t w_t \ell d\boldsymbol{D}_t = \tau_t w_t L_t^{hh}$$

Market clearing. Market clearing implies

1. Asset market: $K_t = A_t^{hh}$
2. Labor market: $L_t^Y + L_t^G = L_t^{hh}$
3. Goods market: $Y_t = C_t^{hh} + I_t$

2. Calibration

1. **Preferences:** $\sigma = \omega = 2$, $\varphi = 1.0$, $\nu = 1.0$
2. **Income process:** $\rho_z = 0.96$, $\sigma_\psi = 0.15$,
3. **Production:** $\Gamma_{ss}^Y = \Gamma_{ss}^G = 1$, $\alpha_{ss} = 0.30$, $\delta = 0.10$

3. Solving the household problem

The envelope condition implies

$$\underline{v}_{a,t+1}(z_{t-1}, a_{t-1}) = \mathbb{E}\left[(1 + r_t^K - \delta) c_t^{-\rho} \,|\, z_{t-1}, a_{t-1}\right] \tag{7}$$

The first order conditions imply

$$c_t = (\beta \underline{v}_{a,t+1}(z_t, a_t))^{-\frac{1}{\sigma}} \tag{8}$$

$$\ell_t = \left(\frac{(1-\tau_t) w_t z_t}{\varphi}\right)^{\frac{1}{\nu}} c_t^{-\sigma/\nu} \tag{9}$$

The household problem can be solved with an extended EGM:

1. Calculate c_t and ℓ_t over end-of-period states from FOCs
2. Construct endogenous grid $m_t = c_t + a_t - (1-\tau_t) w_t \ell_t z_t$
3. Use linear interpolation to find consumption $c^*(z_t, a_{t-1})$ and labor supply $\ell^*(z_t, a_{t-1})$ with $m_t = (1 + r_t) a_{t-1}$
4. Calculate savings $a^*(z_t, a_{t-1}) = (1 + r_t) a_{t-1} + (1-\tau_t) w_t \ell_t^* z_t - c_t^*$
5. If $a^*(z_t, a_{t-1}) < 0$ set $a^*(z_t, a_{t-1}) = 0$ and search for ℓ_t such that $f(\ell_t) \equiv \ell_t - \left(\frac{(1-\tau_t) w_t z_t}{\varphi}\right)^{\frac{1}{\nu}} c_t^{-\sigma/\nu} = 0$ holds and $c_t = (1 + r_t) a_{t-1} + (1-\tau) w_t \ell_t z_t$. This can be done with a Newton solver with an update from step j to step $j+1$ by

$$\begin{aligned}
\ell_t^{j+1} &= \ell_t^j - \frac{f(\ell_t)}{f'(\ell_t)} \\
&= \ell_t^j - \frac{\ell_t - \left(\frac{(1-\tau) w_t z_t}{\varphi}\right)^{\frac{1}{\nu}} c_t^{-\sigma/\nu}}{1 - \left(\frac{(1-\tau) w_t z_t}{\varphi}\right)^{\frac{1}{\nu}} (-\sigma/\nu) \frac{\partial c_t}{\partial \ell_t}} \\
&= \ell_t^j - \frac{\ell_t - \left(\frac{(1-\tau) w_t z_t}{\varphi}\right)^{\frac{1}{\nu}} c_t^{-\sigma/\nu}}{1 - \left(\frac{(1-\tau) w_t z_t}{\varphi}\right)^{\frac{1}{\nu}} (-\sigma/\nu)\, c_t^{-\sigma/\nu-1} (1-\tau) w_t z_t}
\end{aligned}$$