

ECON 210C PROBLEM SET # 5

MINKI KIM

1. PROBLEMS FROM ROMER

1.1. Romer, Problem 6.13.

- (a) Think of an asset that pays $-c$ per unit time when the individual climbs a tree and \bar{u} when the worker is unemployed. In addition, assume that the asset is being priced by risk-neutral investors with required rate of return r . Since the expected present value of lifetime dividends of this asset is the same as the individual's expected present value of lifetime utility, the asset's price must be V_P when the individual is looking for palm trees and V_C when the individual is looking for people with coconuts. For the asset to be held, it must provide an expected rate of return of r . That is, its dividends per unit time, plus any expected capital gains or losses per unit time, must equal rV_P . When the individual is looking for trees, there are no dividends, whereas there is a payoff of $V_C - V_P - c$ when the individual finds a tree and climbs it (which occurs with probability b). Thus,

$$rV_P = b(V_C - V_P - c)$$

- (b) If the individual is looking for others with coconuts, there are no dividends, whereas there is a payoff of $V_P - V_C + \bar{u}$ when someone with a coconut is found, which occurs with probability aL . Thus,

$$rV_C = aL(V_P - V_C + \bar{u})$$

- (c) Substituting the equation from part a into the equation from part b yields

$$V_P = \frac{rV_C}{aL} + V_C - \bar{u} \implies r \times \left(\frac{rV_C}{aL} + V_C - \bar{u} \right) = b \times \left(\frac{rV_C}{aL} + \bar{u} - c \right)$$

which gets us

$$V_C \times \left(\frac{r^2 + raL + rb}{aL} \right) = \bar{u}(r + b) - bc$$

so we have

$$V_C = \frac{aL(\bar{u}(r + b) - bc)}{r^2 + raL + rb}$$

and substituting in gets us

$$V_P = \frac{\bar{u}(r + b) - bc}{r + aL + b} + \frac{aL(\bar{u}(r + b) - bc)}{r^2 + raL + rb} - \bar{u}$$

so we can subtract and simplify to get our final answer

$$V_C - V_P = \frac{bc + aL\bar{u}}{r + aL + b}$$

(d) We have the condition

$$aL \times L = b \times (N - L)$$

which is a quadratic in L that we can use the quadratic formula for (ignoring the negative solution)

$$L = \frac{-b + \sqrt{b^2 + 4abN}}{2a}$$

and use the given substitution to obtain

$$L = \frac{-b + \sqrt{9b^2}}{2a} = \frac{b}{a}$$

(e) We need the cost of climbing to be worthwhile, implying the condition

$$V_C - V_P \geq c$$

but we already have a closed form for $V_C - V_P$ we can use and apply our substitution to, so we have

$$\frac{bc + b\bar{u}}{r + 2b} \geq c$$

and so we can solve for the constraint on c to get

$$c \leq \frac{b\bar{u}}{r + b}$$

for the possible values of c .

(f) It is a best response for no one to climb when no one else climbs (since no trade will occur) as long as climbing is costly, that is when $c > 0$. So any positive c gives an equilibrium where $L = 0$. From earlier, we have the other equilibrium of $L = \frac{b}{a}$ when

$$0 < c \leq \frac{b\bar{u}}{r + b}$$

so this range does imply multiple equilibria. The equilibrium with positive L has higher welfare, which must be the case for climbing to be worthwhile (every climb gives a positive payoff relative to the no climbing case so more climbing means more overall payoff).

1.2. **Romer, Problem 7.10.** We have average price in each time period

$$p_t = (1 - \alpha)(p_{t-1} + \gamma\pi_{t-1}) + \alpha x_t$$

Subtract last period's price from both sides

$$p_t - p_{t-1} = (1 - \alpha)\gamma\pi_{t-1} + \alpha(x_t - p_{t-1})$$

Expand the right side

$$p_t - p_{t-1} = (1 - \alpha)\gamma\pi_{t-1} + \alpha(x_t - p_t + p_t - p_{t-1})$$

Substitute

$$\pi_t = (1 - \alpha)\gamma\pi_{t-1} + \alpha(x_t - p_t + \pi_t)$$

Rearrange to get

$$x_t - p_t = \frac{1 - \alpha}{\alpha} \times (\pi_t - \gamma\pi_{t-1})$$

We now have a new problem for the firm

$$\min_{x_t} \frac{1}{2} \times (x_t - (p_t + \phi y_t))^2 + \sum_{j=1}^{\infty} \beta^j (1 - \alpha)^j \frac{1}{2} E_t \left(x_t + \sum_{k=0}^{j-1} \gamma \pi_{t+k} - \left[p_t + \sum_{k=1}^j \pi_{t+k} + \phi y_{t+k} \right] \right)^2$$

since firms have to set a price today that can cause them a loss today, but they also have to take into account the future, which is both discounted (accounted for with the β term) and where they may be able to adjust prices anyway (hence the $1 - \alpha$ term). The partial indexation means that the price in period t is the previous period's price plus $\gamma\pi_{t-1}$, so we account for all of these changes with the $x_t + \sum_{k=0}^{j-1} \gamma \pi_{t+k}$ term. The profit maximizing price in the future is accounted for with the $p_t + \sum_{k=1}^j \pi_{t+k} + \phi y_{t+k}$ term.

Now we solve the firm's problem using the first order condition

$$x_t - (p_t + \phi y_t) + \sum_{j=1}^{\infty} \beta^j (1 - \alpha)^j E_t \left(x_t + \sum_{k=0}^{j-1} \gamma \pi_{t+k} - \left[p_t + \sum_{k=1}^j \pi_{t+k} + \phi y_{t+k} \right] \right) = 0$$

Now we want to get a geometric series to simplify, but we can't do that with terms inside the expectation. However, the x_t and p_t terms inside the expectation are chosen and known today, so we can pull them out of the expectation and have a new summation to simplify as follows

$$\left[\sum_{j=0}^{\infty} [\beta \times (1 - \alpha)]^j x_t - p_t \right] + \phi y_t + \sum_{j=1}^{\infty} \beta^j (1 - \alpha)^j E_t \left(\sum_{k=0}^{j-1} \gamma \pi_{t+k} - \left[\sum_{k=1}^j \pi_{t+k} + \phi y_{t+k} \right] \right) = 0$$

so we can use the formula for an infinite geometric series to get

$$\frac{x_t - p_t}{1 - \beta(1 - \alpha)} + \phi y_t + \sum_{j=1}^{\infty} \beta^j (1 - \alpha)^j E_t \left(\sum_{k=0}^{j-1} \gamma \pi_{t+k} - \left[\sum_{k=1}^j \pi_{t+k} + \phi y_{t+k} \right] \right) = 0$$

2. QUADRATIC COST OF ADJUSTING PRICES AND EFFECT OF MONEY (ROTEMBERG 1982)

- (a)
- (b)
- (c)
- (d)
- (e)

3. NEW KEYNESIAN MODEL IN DYNARE

- (a)
- (b)
- (c)
- (d)

4. GOVERNMENT SPENDING MULTIPLIERS IN THE NEW KEYNESIAN MODEL (CHRISTIANO, EICHENBAUM AND EVANS 2012)

- (a) The economy is characterized by the following log-linearized equations:

$$\begin{aligned}
 \check{C}_t &= E_t \check{C}_{t+1} - \frac{1}{\psi} (i_t - E_t \pi_{t+1}) \\
 \pi_t &= \beta E_t \pi_{t+1} + \kappa \left(\frac{\check{W}}{P} \right)_t, \quad \kappa = \frac{(1-\theta)(1-\beta\theta)}{\theta} \\
 \left(\frac{\check{W}}{P} \right)_t &= \psi \check{C}_t + \frac{1}{\eta} L_t \\
 \check{Y}_t &= \check{L}_t \\
 \check{Y}_t &= s_g \check{G}_t + (1-s_g) \check{C}_t \\
 i_t &= \phi_\pi \pi_t, \quad \phi_\pi > 1
 \end{aligned}$$

The first equation is a standard Euler equation. The second equation is a recursive formulation of inflation rate, telling us that current inflation is a present value of future marginal costs. The third equation is household's labor supply. The fourth equation denotes aggregate production function. The fifth equation is national account, where s_g is the share the government spending. Finally, the last equation implies that the central bank follows the Taylor rule.

(b) The reduced system is characterized as follows:

$$\begin{aligned}\check{C}_t &= E_t \check{C}_{t+1} - \frac{1}{\psi} (\phi_\pi \pi_t - E_t \pi_{t+1}) \\ \pi_t &= \beta E_t \pi_{t+1} + \kappa \left(\psi \check{C}_t + \frac{s_g}{\eta} \check{G}_t + \frac{(1-s_g)}{\eta} \check{C}_t \right)\end{aligned}$$

We have two endogenous variables (\check{C}_t, π_t) and one exogenous variable (\check{G}_t) .

(c) Assume that government spending has the following dynamics:

$$\check{G}_t = \rho \check{G}_{t-1} + \epsilon_t, \quad \epsilon_t \sim i.i.d. (0, \sigma^2)$$

Since both \check{C}_t and π_t are jump-variables, the only state variable is \check{G}_t . 1 is not a state variable because the model is log-linearized. Since \check{C}_{t-1} and π_{t-1} do not show up in the system, lagged endogenous variables are also not state variables.

(d) Since rational expectation was introduced to the literature, numerous researchers have commented on the multiplicity of solution paths in linear rational expectation models. Since models with infinite number of solutions which are consistent with rational expectation are evidently unusable, seeking for a solution procedure which can single out a unique, bubble-free solution was a natural flow of the literature.

McCallum(1983) suggests a solution procedure called the *minimum state variable (MSV) criterion*. Since the multiplicity (or sunspots) arises from redundant state variables which are unnecessary but not formally inconsistent with rational expectations, he suggests to rule out those state variable from the beginning. In our model, the minimum set of state variables is $\{\check{G}_t\}$. The solution equations for \check{C}_t and π_t are expressed as functions of state variable \check{G}_t :

$$\begin{aligned}\check{C}_t &= c_g \check{G}_t \\ E_t \check{C}_{t+1} &= c_g \rho \check{G}_t \\ \pi_t &= \pi_g \check{G}_t \\ E_t \pi_{t+1} &= \pi_g \rho \check{G}_t\end{aligned}$$

Plugging in these guessed form of solution equations into the system:

$$\begin{aligned}c_g \check{G}_t &= c_g \rho \check{G}_t - \frac{1}{\psi} (\phi_\pi \pi_g \check{G}_t - \pi_g \rho \check{G}_t) \\ \pi_g \check{G}_t &= \beta \pi_g \rho \check{G}_t + \kappa \left(\psi c_g \check{G}_t + \frac{s_g}{\eta} \check{G}_t + \frac{(1-s_g)}{\eta} c_g \check{G}_t \right)\end{aligned}$$

With some algebraic effort, we get

$$\begin{aligned}\pi_g &= \frac{\frac{\kappa}{\eta} (1-\rho) s_g}{(1-\beta\rho)(1-\rho) + \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta} (1-s_g) \right] (\phi_\pi - \rho)} \\ c_g &= \frac{-\frac{\kappa}{\eta\psi} (\phi_\pi - \rho) s_g}{(1-\beta\rho)(1-\rho) + \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta} (1-s_g) \right] (\phi_\pi - \rho)}\end{aligned}$$

(e) Following the solution obtained in (d),

$$\begin{aligned}
\frac{dY}{dG} &= 1 + \frac{dC}{dG} = 1 + \frac{1-s_g}{s_g} \frac{d\check{C}}{d\check{G}} \\
&= 1 + \frac{c_g(1-s_g)}{s_g} \\
&= 1 - \frac{\frac{\kappa}{\eta\psi}(\phi_\pi - \rho)(1-s_g)}{(1-\beta\rho)(1-\rho) + \kappa \left[1 + \frac{1}{\eta\psi}(1-s_g) \right] (\phi_\pi - \rho)} \\
&= 1 - \frac{\frac{\kappa}{\eta\psi}(\phi_\pi - \rho)(1-s_g)}{(1-\beta\rho)(1-\rho) + \kappa(\phi_\pi - \rho) + \frac{\kappa}{\eta\psi}(1-s_g)(\phi_\pi - \rho)} \\
&\quad \text{Let } \frac{\kappa}{\eta\psi}(\phi_\pi - \rho)(1-s_g) = A \\
&= 1 - \frac{A}{(1-\beta\rho)(1-\rho) + \kappa(\phi_\pi - \rho) + A}
\end{aligned}$$

(f) Since $(1-\beta\rho)(1-\rho) + \kappa(\phi_\pi - \rho) > 1$, $dY/dG < 1$. The government spending multiplier is smaller than one because the Taylor rule effectively stabilizes the inflation, hence cools down the economy.

(g) When $\phi = 0$, the government spending multiplier is:

$$\begin{aligned}
\frac{dY}{dG} &= 1 + \frac{\frac{\kappa}{\eta\phi}\rho(1-s_g)}{(1-\beta\rho)(1-\rho) - \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta}(1-s_g) \right] \rho} \\
&> 1
\end{aligned}$$

So the government spending multiplier is larger than 1 even for a very low persistence shock. This is because the monetary policy is not raising nominal interest rate enough to make the real interest rate $r_t = i_t - E_t\pi_{t+1}$ also rise. Since the real interest rate is too low, even a small demand shock can make a ripple effect.

(h) Assuming $\phi_\pi = 0$, or generally any value of ϕ_π which violates the Taylor principle ($\phi_\pi > 1$) is problematic because the model becomes explosive.

(i) The economy in the ZLB is characterized by the following system of equations:

$$\begin{aligned}
\check{C}_t &= E_t\check{C}_{t+1} - \frac{1}{\psi}(i_t - E_t\pi_{t+1}) \\
\pi_t &= \beta E_t\pi_{t+1} + \kappa \left(\frac{\check{W}}{P} \right)_t, \quad \kappa = \frac{(1-\theta)(1-\beta\theta)}{\theta} \\
\left(\frac{\check{W}}{P} \right)_t &= \psi\check{C}_t + \frac{1}{\eta}L_t \\
\check{Y}_t &= \check{L}_t \\
\check{Y}_t &= s_g\check{g} + (1-s_g)\check{C}_t \\
i_t &= -\bar{i}
\end{aligned}$$

The reduced 2-equation system is:

$$\begin{aligned}\check{C}_t &= E_t \check{C}_{t+1} - \frac{1}{\psi} (-\bar{i} - E_t \pi_{t+1}) \\ \pi_t &= \beta E_t \pi_{t+1} + \kappa \left(\psi \check{C}_t + \frac{s_g}{\eta} \tilde{g} + \frac{(1-s_g)}{\eta} \check{C}_t \right)\end{aligned}$$

Substituting guessed forms of solutions (without constant terms) into the system yields:

$$\begin{aligned}c_g^{ZLB} \tilde{g} &= p c_g^{ZLB} \tilde{g} - \frac{1}{\psi} (-\bar{i} - p \pi_g^{ZLB} \tilde{g}) \\ \pi_g^{ZLB} \tilde{g} &= \beta p \pi_g^{ZLB} \tilde{g} + \kappa \left(\psi c_g^{ZLB} \tilde{g} + \frac{s_g}{\eta} \tilde{g} + \frac{(1-s_g)}{\eta} c_g^{ZLB} \tilde{g} \right)\end{aligned}$$

Solving the system gives us

$$\begin{aligned}\pi_g &= \frac{\frac{\kappa}{\eta}(1-p)s_g}{(1-\beta p)(1-p) - \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta}(1-s_g) \right] p} \\ c_g &= \frac{\frac{\kappa}{\eta\psi} p s_g}{(1-\beta p)(1-p) - \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta}(1-s_g) \right] p}\end{aligned}$$

(j) Following the solution obtained in (i),

$$\begin{aligned}\frac{dY}{dG} &= 1 + \frac{dC}{dG} = 1 + \frac{1-s_g}{s_g} \frac{d\check{C}}{d\tilde{G}} \\ &= 1 + \frac{c_g^{ZLB}(1-s_g)}{s_g} \\ &= 1 + \frac{\frac{\kappa}{\eta\psi} p(1-s_g)}{(1-\beta p)(1-p) - \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta}(1-s_g) \right] p}\end{aligned}$$

(k) Given $(1-\beta p)(1-p) - \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta}(1-s_g) \right] p > 0$, the government spending multiplier is always larger than 1. This is because the Taylor rule is not working at the ZLB, so the monetary policy does not stabilize the economy.

(l) Compare the two government spending multipliers

$$\begin{aligned}\text{in (g): } \frac{dY}{dG} &= 1 + \frac{\frac{\kappa}{\eta\phi} \rho(1-s_g)}{(1-\beta\rho)(1-\rho) - \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta}(1-s_g) \right] \rho} \\ \text{in (k): } \frac{dY}{dG} &= 1 + \frac{\frac{\kappa}{\eta\psi} p(1-s_g)}{(1-\beta p)(1-p) - \frac{\kappa}{\psi} \left[\psi + \frac{1}{\eta}(1-s_g) \right] p}\end{aligned}$$

Those two multipliers are the same when $p = \rho$. In (g), monetary policy is ineffective indefinitely. Thus the persistence of the government spending shock determines the size of the multiplier. In (k), on the other hand, the probability

of escaping from the ZLB determines the size of the multiplier, since $\rho = 1$ as long as the economy is trapped in the ZLB.