Question 1: Consider a modified version of the continuous-time Solow growth model where the aggregate production function is

$$F(K, L, Z) = L^\beta K^\alpha Z^{1-\alpha-\beta},$$

where $Z$ is land, available in fixed inelastic supply. Assume that $\alpha + \beta < 1$, capital depreciates at the rate $\delta$, and there is an exogenous saving rate of $s$.

1. First suppose that there is no population growth. Find the steady-state capital-labor ratio and the steady-state output level. Prove that the steady state is unique and globally stable.

2. Show that, in the steady-state equilibrium, there is a monotonic relationship between the interest rate and the saving rate of the economy. Using this result, show that there exists a saving rate $s^*$ such that above this, the interest rate is negative. Show that when the interest rate is negative, starting from the steady-state equilibrium, it is possible to reallocate resources so that consumption increases at all points in time. Explain what this means and why such a possibility is present in this model.

3. Now suppose that there is population growth at the rate $n$, that is, $\dot{L}/L = n$. Does a steady-state equilibrium exists? What happens to the capital-labor ratio and output level as $t \to \infty$? What happens to returns to land and the wage rate as $t \to \infty$?

4. Would you expect the population growth rate $n$ or the saving rate $s$ to change over time in this economy? If so, how? What other adjustments might you expect in this economy as $t \to \infty$?

Question 2: Consider the discrete-time Solow growth model with constant population growth at the rate $n$, no technological change and depreciation rate of capital equal to $\delta$. Assume that the saving rate is a function of the capital-labor ratio, thus given by $s(k)$.

1. Suppose that $f(k) = Ak$ and $s(k) = s_0k^{-1} - 1$. Show that if $A + \delta - n = 2$, then for any $k(0) \in (0, As_0/(1+n))$, the economy immediately settles into an asymptotic cycle and continuously fluctuates between $k(0)$ and $As_0/(1+n) - k(0)$. [Suppose that $k(0)$ and the parameters are given such that $s(k) \in (0, 1)$ for both $k = k(0)$ and $k = As_0/(1+n) - k(0)$].
2. Now consider more general continuous production function \( f(k) \) and saving function \( s(k) \), such that there exist \( k_1, k_2 \in \mathbb{R}^+ \) with \( k_1 \neq k_2 \) and

\[
\begin{align*}
    k_2 &= \frac{s(k_1)f(k_1) + (1 - \delta)k_1}{1 + n} \\
    k_1 &= \frac{s(k_2)f(k_2) + (1 - \delta)k_2}{1 + n}.
\end{align*}
\]

Show that when such \((k_1, k_2)\) exist, there may also exist a stable steady state.

3. Prove that such cycles are not possible in the continuous-time Solow growth model for any (possibly non-neoclassical) continuous production function \( f(k) \) and continuous \( s(k) \).

4. What does the result in parts 1-3 imply for the approximations of discrete time by continuous time in the Solow model (suggested in Section 2.4 of the textbook)? What does this imply for the cycles in parts 1 and 2?

5. Show that if \( f(k) \) is nondecreasing in \( k \) and \( s(k) = k \), cycles as in parts 1 and 2 are not possible in discrete-time either.

**Question 3:** Consider the Solow growth model with constant saving rate \( s \) and depreciation rate of capital equal to \( \delta \). Assume that population is constant and the aggregate output is given by the CES production function

\[
F(A_K(t)K(t), A_L(t)L) = \left[ \gamma (A_K(t)K(t))^{\frac{\sigma-1}{\sigma}} + (1 - \gamma)(A_L(t)L)^{\frac{\sigma-1}{\sigma}} \right]^\frac{\sigma}{\sigma-1},
\]

where \( \dot{A}_L(t)/A_L(t) = g_L > 0 \) and \( \dot{A}_K(t)/A_K(t) = g_K > 0 \). Suppose the elasticity of substitution between capital and labor is less than one, \( \sigma < 1 \), and capital-augmenting technological progress is faster than labor-augmenting progress, \( g_K \geq g_L \). Show that as \( t \to \infty \), the economy converges to a BGP where the share of labor in national income is equal to 1, and capital, output and consumption all grow at the rate \( g_L \). In light of this result, discuss the claims in the literature that capital-augmenting technological change is inconsistent with balanced growth.

**Question 4:** Consider the basic Solow model in continuous time and suppose that \( A(t) = A \), so that there is no technological progress of the usual kind. However, assume that the relationship between investment and capital accumulation is modified to

\[
\dot{K}(t) = q(t)I(t) - \delta K(t),
\]

where \( [q(t)]_{t=0}^{\infty} \) is an exogenously given time-varying process. Intuitively, when \( q(t) \) is high, the same investment expenditure translates into a greater increase in the capital stock. Therefore, we can think of \( q(t) \) as the inverse of the relative prices of machinery to output. When \( q(t) \) is high, machinery is relatively cheaper, and thus suppose that \( \dot{q}(t) > 0 \).

1. Suppose that \( \dot{q}(t)/q(t) = \gamma_K > 0 \). Show that for a general production function, \( F(K,L) \), there exists no steady-state equilibrium.
2. Now suppose that the production function is Cobb-Douglas, \( F(K, L) = K^\alpha L^{1-\alpha} \), and characterize the unique steady-state equilibrium.

3. Show that this steady-state equilibrium does not satisfy the Kaldor fact of constant \( K/Y \). Is this a problem? [Hint: how is “\( K \)” measured in practice? How is it measured in this model?].