Faculty of Economic Sciences
HSE University

Advanced Macroeconomics-2 (Master's level)

1. **Course Description**

Abstract: This course is a master's level course on Macroeconomic theory. It aims to instill a firm understanding of the language of modern macroeconomics. Macroeconomics addresses "big" questions by asking: Why do economies grow over time, and what factors do determine the speed of economic growth? Why do we have business cycles, and how should monetary and fiscal policies react to short-run fluctuations? The course will seek the answers to these questions by applying modern tools to the analysis of macroeconomic processes.

The evolution of total output can be conceptually decomposed into a long-term trend and business-cycles around this trend. Macroeconomists have developed two distinct groups of theories (e.g. employing different sets of assumptions) depending on whether they are interested in explaining the short-run dynamics or the long-run dynamics in the economy. Similarly, this course is divided into two parts.

The first part of the course is devoted to the process of trend-growth in output per capita. It offers an overview of a range of standard growth models by looking at their theoretical relevance and empirical success in explaining different aspects of the process of long-run economic growth and the emergence of income differences across countries. The second part of the course is devoted to the issues in a short-run macro. It presents basic theories of business cycle fluctuations with reference to the conduct of macroeconomic policies. The primary focus is on the main tools that are used for construction of business cycle models and their application to fiscal and monetary policies.

2. **Learning Objectives**
   - to provide students with the stylized facts about economic growth and business cycle and the main questions macroeconomists try to address;
   - to present basic theories of economic growth and business cycle;
   - to introduce students to core concepts and standard methodological tools that lay the foundation of modern macroeconomic analysis.

3. **Learning Outcomes:** At the end of the course, students are expected to show
   - an awareness of the main debates and approaches in the literature on economic growth and business cycle that will help them decide on the direction of their future research;
   - a basic understanding of the workings of standard macroeconomic models that will enable them to learn and work with more advanced models in the future.
4. **Grading System**

   The grade for Advanced Macroeconomics-2 is determined by:
   - Two written in-class tests (one at the end of each module)
   - Written in-class mini-test work based on home assignments
   - Quizzes
   - Class participation

Additionally, two home assignments in each module will contain problems that will ask students to apply analytical skills to the analysis of the models (and their slightly modified versions) covered in the lectures, i.e. solving the models, discussing their predictions and summarizing the lessons that can be drawn from them. These home assignments will not count towards the final course score, but they will form the basis for mini-test work held during the course and controls at the end of each module.

Grading formula:
Course Grade (CG) = 0.4 * [Final exam] + 0.2 * [Mid-term exam for part Growth] + 0.15 * [Quizzes] + 0.15 * [Mini-test work] + 0.1 * [Class participation]

[Final exam] and [Mid-term exam for part Growth] are written controls at at the end of each module that will test the material covered in the course and contain problems similar to those in home assignments, seminars and practice problems. [Final exam] will include problems from both parts of the course.

[Mini-test work] is a written control in class that will contain problems that are based on home assignments.

[Quizzes] will contain short questions testing students' knowledge of the stylized facts and core concepts mentioned in the lectures.

[Class participation] grade will depend on attendance and active involvement in the seminars.

A 100-points scale will be used for all assignments and tests. Course grade (CG) will be translated into 10-points scale by rounding (CG+5)/10 to the nearest integer (where x.5 is mapped to x+1 for x=0,….,9).

Topics for Module 2

Outline of Module 2:

5. **Course Plan:** The second part of the course is 8 weeks long in Module 2. Each week, there will be two lectures and one seminar.
6. **Reading List for Module 2 (Economic Growth)**

Required textbooks:

- Advanced Macroeconomics by David Romer

More advanced supplements:

- Acemoglu (2010) Introduction to modern economic growth. Princeton University Press.
- Aghion P. Howitt P. Endogenous growth theory. MIT. (1999)
- Macroeconomic Theory, Lecture notes, by Dietrich Vollrath (2017)
- A Theory of Economic Growth, Dynamics and Policy in Overlapping Generations by D.De la Croix, P. Michel (2002)

Scholarly articles as assigned in this syllabus

Weeks 1-2 (4 meetings): Introduction to modern economic growth. Solow-Swan model.

- Stylised facts and main questions about Economic Growth
- Solow Swan model without Technological Progress
  - Main assumption and steady state properties. Existence and uniqueness of equilibrium
  - Formal analysis of transitional dynamics
  - Implications of the Solow model, consumption and welfare.
- Technological change in the Solow model
  - Solow model with technological change in descrete and continuous time
  - The simple AK model and its predictions.
  - Balanced growth. Uzawa's theorem.
  - Solow model and data. Accounting for cross-country differences in incomes and growth rates.

Readings:

1. Romer D. (2009), Advanced Macroeconomics, Chapter 1.
2. Jones (2016): The Facts of Economic Growth, Handbook of Macroeconomics
3. Acemoglu (2009): Introduction to Modern Economic Growth, chapter 1-3

Weeks 3-4 (4 meetings): Savings and supply of capital: Fisher model and OLG model

- Baseline intertemporal choice model
  - Income and substitution effect, wealth effect

        - Formal solution of the model, intuition for consumption Euler equation
        - The model for CRRA utility function
    - Canonical Overlapping generation model with two –period lived agents
        - Basic Two-Generations model (OLG)
        - A more general version of OLG model with CRRA utility and Cobb-Douglas technology
        - Dynamic inefficiency and the problem of overaccumulation of capital
        - The effect of social security systems of capital accumulation
        - An OLG model with impure altruism
    - Galor –Zeira OLG model: inequality and growth.

Readings:

1. Romer D. (2009), Advanced Macroeconomics, Chapter 2.
2. Acemoglu (2009): Introduction to Modern Economic Growth, chapter 9
3. Galor, O., & Zeira, J. (1993). Income distribution and macroeconomics. The review of economic studies, 60(1), 35-52.
4. A theory of Economic Growth, Dynamics and Policy in Overlapping Generations by D.De la Croix, P. Michel. Chapter 1, 2.

Weeks 5-6 (4 meetings): Neoclassical Growth Models: Ramsey-Cass-Koopmans model.

- The foundations of Ramsey model
    - Consumption problem of the infinitely lived agents (descrete time)
    - Consumption problem of the infinitely lived agents (continuous time)
- Ramsey model (baseline version), the centralized version.
- Ramsey model (baseline version), decentralized solution and comparative dynamics.
- Ramsey model with technological progress and population growth. Basic results and comparative dynamics.

Readings:

Romer D. (2009), Advanced Macroeconomics, Chapter 2.
Acemoglu (2009): Introduction to Modern Economic Growth, chapter 8

Week 7-8 (4 meetings): Endogenous growth models

- Facts about technological progress. The simplest endogenous growth model
- The Romer growth model (1990), the foundations, solution and basic results
- Schumpeterian endogenous growth model, foundations, solution and basic results
- Technology transfer and cross-country income divergence
- Allocation and growth.

Readings:

- Acemoglu (2010) Introduction to modern economic growth. Princeton University Press. Ch 8
- Aghion P. Howitt P. Endogenous growth theory. MIT. (1999). Ch 2
- Romer (1986) Increasing Returns and Long-Run Growth. Journal of Political Economy
- Romer (1990) Endogenous Technical Change. Journal of Political Economy
- Jones (1995) R&D Based Models of Economic Growth

Topics for Module 3

Outline of Module 3:

7. **Course Plan:** The second part of the course is 8 weeks long in Module 3. Each week, there will be two lectures and one seminar.
8. **Reading List for Module 2 (Business Cycle)**

Required textbooks:

- Dynamic Macroeconomics (The MIT Press), by George Alogoskoufis
- The ABCs of RBCs (Harvard University Press, 2008), by George McCandless

- Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework (Princeton University Press, 2008), by Jordi Gali.

More advanced supplements:

- Ljungqvist and Sargent (2018): Recursive Macroeconomic Theory. 4th Edition
- Stokey and Lucas with Prescott (1989): Recursive Methods in Economic Dynamics
- Niepelt (2019): Macroeconomic Analysis

Scholarly articles as assigned in this syllabus

Week 1 (2 meetings): Preliminaries and a two-period consumption-saving model

- Traditional vs modern macroeconomics: historical background
- Two-period consumption-saving model
    - Framework 1: One Type of Agent, No Uncertainty
    - Framework 2: One Type of Agent, Stochastic Aggregate Endowment
    - Framework 3: Two Types of Agents, No Uncertainty
    - Framework 4: Two Types of Agents, Stochastic Individual Endowments
- Infinite-horizon intertemporal choice problem
    - A Lagrangian Formulation

Readings:

1. Alogoskoufis, Ch. 1.1.
2. Mankiw, N. Gregory, "A Quick Refresher Course in Macroeconomics," Journal of Economic Literature, 1990, 28, pp. 1645-1660.
3. Lucas, E. Robert, "Econometric policy evaluation: A critique," in Carnegie-Rochester conference series on public policy, 1976, vol. 1, no. 1, pp. 19-46.
4. Barbara, Mace; "Full Insurance in the Presence of Aggregate Uncertainty," Journal of Political Economy, 1991, 99 no. 5, pp. 928-956.

Week 2 (2 meetings): A two-period competitive model with production

- The model with capital but without endogenous labor
- The model with endogenous labor but without capital
- Elasticities of substitution
    - Intertemporal elasticity of substitution of consumption
    - Frisch elasticity of labor supply

Readings:

1. Alogoskoufis, Ch. 2, Sections 2.1–2.5.

Weeks 3-4 (4 meetings): Dynamic programming with applications to the Neoclassical Growth Model

- Recursive approach to the Neoclassical Growth (Ramsey-Cass-Koopmans) model
- Key concepts: principal of optimality, state and control variables, Bellman equation, value function etc
- Solution methods for finite-period and infinite-period dynamic programming
- Links to computational methods and theoretical properties
- Inclusion of uncertainty into the stochastic growth model
    - Representation of uncertainty and stochastic processes
    - Markov process and Markov chain
    - Conditional and unconditional probabilities
    - Stationary distribution
- Stochastic Dynamic Programming
- Solution Methods

Readings:

1. McCandless, Ch. 4-5.
2. Mathematical background (for additional details): Ljungqvist and Sargent (3-rd edition), Ch. 2.1-2.3 and Appendix A in Part VII

3. Campbell, John, “Inspecting the Mechanism: An Analytical Approach to the Stochastic Growth Model,” Journal of Monetary Economics, 1994, 33, pp. 463-506.
4. King, R. and Sergio Rebelo, “Resuscitating Real Business Cycles,” Chapter 14, Volume 1B, Handbook of Macroeconomics, 1999, J.Taylor and M.Woodford eds, North Holland, pp.927-1007.
5. (optional) Stokey and Lucas, Ch. 3 and Ch. 4.2.

Week 5 (2 meetings): Real Business Cycle Model (RBC)
- Business Cycle
- Measurement of business cycle
- Quantitative evaluation of models
- Calibration of a model
- Decentralization of the RBC model
- Comparison of data with model predictions

Readings:
1. McCandless, Ch. 6.
2. Kydland and Prescott (1990). Business cycles: Real facts and a monetary myth.
3. King and Rebelo (1999). Resuscitating real business cycles.

Week 6 (2 meetings): Fiscal policy in the RBC model
- Lump sum and distortionary taxes
- Indeterminacy of taxes and debt
- Ricardian equivalence
- Responses to shocks depending on the tax structure

Readings:
1. Alogoskoufis, Ch. 2.7
2. Baxter, Marianne and Robert King. “Fiscal Policy in General Equilibrium,” American Economic Review, 1983.
3. Chamley, Christophe, “Efficient tax reform in a dynamic model of general equilibrium,” The Quarterly Journal of Economics, 1985.

Weeks 7-8 (4 meetings): Nominal prices, money, and New Keynesian model
- Benchmark monetary model with flexible prices
  - Perfect competition
  - Monopolistic competition, as precursor to sticky prices
- Basic model of money demand
- Money neutrality
- Background on New Keynesian models.
- The basic new Keynesian model
  - Sticky prices, output gaps, and the new Keynesian Phillips curve.
  - Equilibrium dynamics and response to shocks.
- Policy
  - Optimal policy in the basic new Keynesian model.
  - Optimal policy implementation, equilibrium stability and uniqueness.

Readings:
1. Gali, Ch. 2, 3, and 4.
2. McCandless, Ch. 9.
3. Clarida, Richard, Jordi Gali and Mark Gertler, “The Science of Monetary Policy: A New Keynesian Perspective,” Journal of Economic Literature 37, December 1999, pp. 1661-707. Sections 1-3.
4. Woodford, M. (2010). Optimal monetary stabilization policy. Handbook of Monetary Economics, 3, 723-828.

Mid-term. 2024. Macroeconomics. FES. 130 minutes. Closed book.

1 Task 1 (30 points). Exogenous and endogenous technological progress

Each of three tasks values 10 points.

1. (10 points) There are two countries, A and B described by the Solow model. In both countries the production function (in per capita terms) is $y = k^{1/3}$, and the rate of depreciation is 0.04 and population growth rate is zero. There is no technological change. In country A, the saving rate (s) is 0.16 in B, the saving rate is 0.36. Find the ratio of output per capita and consumption per capita between two economies ($y_A/y_B, c_A/c_B$). Illustrate your answer on the main diagram of the Solow model.

2. (10 points) An individual lives for two periods of time. She has the following instantaneous utility function $u(c) = c^{0.5}$. The individual has incomes for both periods are constant and equal to w, the interest rate is given and equals $R = 1+r$. Individual maximizes the flow of utilities $u(c_1) + 0.8u(c_2)$. If the gross interest rate (R) increased by 10%, and before the shock the optimal savings was zero, what would be the new level of consumption in proportion ot the income w in the first period, second period? Argument and illustrate your answer on the main diagram

3. (10 points). Let us consider the extension of the Solow model without technological progress with the government spendings. Suppose that the government taxes the income of individuals and spends this money on non-productive issues. More specifically, the main dynamic equation is $\dot{k} = sy - (n + \delta)k - g$, where the amount g is the government spending per capita. How the increase in g affects the dynamics of output per capita, consumption per capita, interest rates, wages? Argument and illustrate your answer on the main diagram and on time-variable diagrams.

2 Task 2 (30 points). OLG and Pension Systems

Consider the standard OLG model in which each household lives for two periods: youth (y) and old age (o). Life-time utility function takes the form of $U = \ln(c_y) + \beta \cdot \ln(c_o)$, where $\beta \in (0, 1)$ is the time-discount factor. In the youth a household works, earns the wage (w), consumes (c_y) and saves (s). Individual labour supply is perfectly inelastic and equals to one. In the old age a household spends savings plus interest payments $s \cdot (1 + r_{t+1})$ on consumption (c_o). Each household seeks to maximize his own utility.

Firms hire labour and rent the capital in order to produce the final good. Each firm seeks to maximize its' own profit. Production function in per worker terms takes the form of $y_t = \sqrt{k_t}$, where y_t is the output per worker and k_t is the capital per worker. Depreciation rate for one period equals to $\delta = 1$. Labour market, capital market and final good market are perfectly competitive. One period growth rate of population equals to $n > 0$. There is no technological growth.

PART I. FULLY FUNDED PENSION SYSTEM **(15 points)**

Assume an economy with Fully-Funded (FF) pension system. In addition to voluntary savings each young household must do obligatory payments in the pension fund in the amount of $m > 0$. Government invests the sum of all obligatory payments in capital. In the old age each household gets obligatory payment plus interest payments $(1 + r_{t+1}) \cdot m$ back.

1. (6 points) Set up utility maximization problem of a household and solve it for optimal s as a function of parameters of the model. How does the optimal s depend on m? Explain you answer.

2. (6 points) Derive the capital accumulation equation in per worker terms $k_{t+1}(k_t)$;

3. (3 points) Derive the steady state level of capital per worker in the economy. Show explicitly how the steady state level of capital depends on obligatory payment m. Provide a full economic intuition of such a result.

PART II. PAY-AS-YOU-GO PENSION SYSTEM **(15 points)**

Assume an economy with Pay-As-You-Go (PAYG) pension system. In addition to voluntary savings each young household must do obligatory payments in the pension fund in the amount of $x > 0$. Government equally distributes the sum of all obligatory payments among current old households in the same period.

1. (4 points) Set up utility maximization problem of a household and solve it for optimal s as a function of parameters of the model. How does the optimal s depend on x?

2. (6 points) Derive the capital accumulation equation in per worker terms $k_{t+1}(k_t, k_{t+1}, x)$. Explain intuitively, how will the steady state level of capital depend on obligatory payment x.

3. (5 points) Government wants to achieve Golden Rule Steady State. Find the appropriate level of capital per worker and value of x.

3 Task 30 (30 points). Ramsey model

In US and European economies TFP growth (g) was lower after the 2008 crises than in the previous years. Let us study the effect of this shock on the aggregate dynamics in the Ramsey model. Consider the Ramsey model without technological progress in the continuous time. The utility function of individual is given by $\int_0^\infty c^{1-\sigma}/(1-\sigma)e^{-(\theta-n)t}$. The budget constaint of the individual is $\dot{\tilde{a}} = (r-n-g)\tilde{a} + \tilde{w} + \tilde{x} - \tilde{c}$. Where a - the amount of assets, w - wage rate, x - other payments, c - consumption. $\tilde{}$ defines variables per efficient labor.

1. Prove that the objective function can be represented as $\int_0^\infty \tilde{c}^{1-\sigma}/(1-\sigma)e^{-(\theta-n-g(1-\sigma))t}$, if the technological progress has the constant pace g. (5 points)

2. Formulate the optimization problem for the individual. Write down the Hamiltonian in current values. Find FOC and Euler equation (10 points)

3. Suppose that the technological progress declines at some point t_0 unexpectedly and permantly. What will be dynamics of consumption and capital per effective labor. Illustrate it on the main diagrams and on the diagrams (time-variable) (5 points)

4. Suppose that the technological progress declines at some point t_0 unexpectedly and temporaraly (until the point t_1). What will be dynamics of consumption and capital per effective labor. Illustrate it on the main diagrams and on the diagrams (time-variable). (5 points)

5. What will be your predictions on the dynamics of interest rates, logarithm of output per capita in both previous cases. Argument your answer (5 points)

4 Task 4 (30 points). Schumpeterian model

Consider the following endogenous growth model. There is only one final good and a single intermediate input. The production function is $Y_t = A_t^\psi \cdot L^{1-\alpha} \cdot x_t^\alpha$, where $\alpha \in (0;1)$ and $\psi \in (0;1]$. Final good not used in intermediate good production is available for consumption and research. To produce one unit of intermediate input one needs to use one unit of final output.

1. (6 points) Formulate the final producer problem of profit maximization. Find the demand function for intermediate inputs;

2. (6 points) Formulate the monopolist's problem of the production of intermediate input. Find the equilibrium quantity of intermediate input;

3. (6 points) What is the equilibrium level of output, GDP and profit?

Suppose that in each period there is a person (entrepreneur), who can invent an innovation. If successful, the quality of intermediate good increased by γ, so that $A_t = \gamma \cdot A_{t-1}$, where $\gamma > 1$. The probability of success is $\phi(n) = (\frac{R}{A^*})^\sigma$, where $\sigma \in (0;1)$, R - research efforts, $A^* = \gamma A_t$ - the desired level of technology. If the entrepreneur innovates, she becomes the monopolist on the market, otherwise a randomly selected person will produce the last period product with productivity $A_t = A_{t-1}$.

4. (6 points) Formulate the problem of innovator to find optimal research expenditures R_t. Find the equilibrium research efforts and probability of innovations.

5. (6 points) What is the equilibrium growth rate in the model. Find and explain the main determinants of the growth rate.

Advanced Macro-2 for Master's Students
Sample Final Exam
150 Minutes, Closed-Book

General information: This sample final exam consists of problems from both modules. The second module's material (Economic growth) constitutes 20% of the final exam. The second module's material (Business cycle) constitutes the remaining 80% of the final exam.

Problem 1 (20 points). Economic growth

(a) (10 points) Let us consider a variant of the Solow model without technological progress. In the model, the government imposes taxes on the income of individuals to finance non-productive government spending. The tax rate is denoted by τ.

- How does a decrease in τ affect the dynamics of output per capita, consumption per capita, interest rates, and wages? Justify your answer.
- Illustrate your answer on the main diagram of the model (draw gross investment, capital dilution and output curves before and after the shock) and on time-variable diagrams for all four variables (log output per capita, log consumption per capita, interest rate, and log wages).

(b) (10 points) In the Romer model of endogenous technological progress, the process of technological progress is given by $\dot{A} = A^{0.5} L_R$, where L_R is the share of researchers in the population. The population grows at the rate n.

- Find the steady state level of technological progress.

Suppose that L_R will increase by 10% (increased by 1.1 times).

- Calculate the effect of this change on technological progress at the moment of the shock (on impact).
- Calculate its effect on the steady state level of technological progress.
- Illustrate your answers on the main diagram of the model (g_A on the horizontal axis, $\dot{g}_A/g_A$ on the vertical axis).

Problem 2 (35 points)

Consider an infinite-horizon deterministic growth model. The (representative) consumer has a time-separable preference with the discount factor $\beta \in (0,1)$, i.e.

$$\sum_{t=0}^{\infty} \beta^t \ln(c_t),$$

where c_t is consumption. Consumers are endowed with one unit of time. The production technology is:

$$y_t = Ak_t^{\alpha} n_t^{1-\alpha} h_t^{1-\alpha},$$

where k_t is the physical stock, n_t is labor input, and h_t is human capital stock. There is a full depreciation of both physical and human capital in one period, i.e. $\delta = 1$. As a result, the resource constraint is

$$c_t + k_{t+1} + h_{t+1} = y_t.$$

At the beginning of $t = 0$, $k_0 > 0$ and $h_0 > 0$ are given.

(a) (10 points) Write down the Bellman Equation for the social planner's decision problem. Derive the Euler Equation from the Bellman Equation.

(b) (13 points) Solve the policy function for (k', h') from the Euler equation in the following steps. (1) Conjecture a functional form of the policy function; (2) Verify that your conjecture satisfies the Euler Equation. Write down the equations which determine the coefficients of the conjecture (but you do NOT need to solve the equations).

(c) (12 points) Solve the value function from the Bellman equation in the following steps. (1) Conjecture a functional form of the value function; (2) Solve the policy function from the FOC, based on the conjectured value function; (3) Verify that your conjecture has the right functional form. Write down the equations which determine the coefficients of the conjecture (but you do NOT need to solve the equations).

Problem 3 (20 points)

Consider a one-sector real business cycle model. The household is endowed with 1 unit of time in every period. The preference of the representative household is given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(c_t - \gamma \frac{n_t^{1+\eta}}{1+\eta}\right)^{1-\sigma} - 1}{1-\sigma} \right],$$

where $c_t > 0$ and $n_t \in [0,1]$ are private consumption and labor hours, respectively, $\gamma > 0$ and $\eta > 0$.

The technology is given by

$$y_t = z_t k_t^{\alpha} n_t^{1-\alpha},$$

where z_t is a shock to technology. The aggregate resource constraint is

$$c_t + i_t = y_t.$$

Unlike the standard RBC model, the capital accumulates according to

$$k_{t+1} = (1-\delta)k_t + \theta_t i_t,$$

where $\delta \in (0,1)$ is the depreciation rate, and $\theta_t > 0$ is the productivity of transforming the investment into the capital stock.

Both z_t and θ_t are stochastic and evolve according to the Markov chains with the means normalized to 1. Shocks z_t and θ_t are independent of each other. At the beginning of $t = 0$, $k_0 > 0$ is given.

(a) (10 points) Write the Bellman equation of the social planner's problem of maximizing the welfare of the household. Derive the FOCs and the Euler equation characterizing the intertemporal and intratemporal optimization problems.

(b) (10 points) Suppose that the average behavior of the real-world data can be captured by a social planner solution defined in Part (a). Use the following observations together to calibrate the parameter γ. Be sure to derive the exact formula for γ. You can assume that you know η.

   (i) Capital's share of income is 36%.

   (ii) The average value of the capital-output ratio (in annual terms) is 2.

   (iii) Households work (on average) one-third of their total available time.

Problem 4 (25 points)

Consider a monetary model with flexible prices. The representative household maximizes

$$\max_{C_t, N_t, K_{t+1}, B_{t+1}, M_t} E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \ln C_t + \theta \ln(1-N_t) \right\},$$

subject to the budget constraint

$$C_t + K_{t+1} - (1-\delta)K_t + \frac{M_t - M_{t-1}}{P_t} + \frac{B_{t+1} - B_t}{P_t} = w_t N_t + R_t K_t + i_{t-1}\frac{B_t}{P_t} - T_t$$

and the constraint that the household stores money to finance consumption of goods, i.e.

$$M_{t-1} \geq P_t C_t,$$

where C_t is consumption, K_t is capital, B_t is nominal bonds, P_t is the price level, M_t is money, w_t is the real wage rate, N_t is labor, R_t is the real return on capital (rental rate), i_{t-1} is the nominal interest rate between $t-1$ and t, and T is a lump sum tax.

(a) (5 points) Derive the first-order-conditions.

(b) (10 points) Suppose that M_{t-1} is always greater than $P_t C_t$. Calculate the nominal interest, i_t. Explain the value intuitively.

(c) (10 points) Now suppose that $M_{t-1} = P_t C_t$. Find below the impulse response functions of the variables to an increase in the growth rate of money.

Explain the economic intuition and underlying forces that are responsible for the dynamics of

(i) Consumption.

(ii) Labor and wage rate.

(iii) Output and investment.

Hint: Think about the role of money in this economy. What is its value? Use the impulse response of the price level and link it to the consumption-leisure choice. What is the effect on λ?