Macrofinance - FIN406 Dr. Simon Tièche: simon.tieche@epfl.ch
Fall 2022 Dr. Stelios Tsiaras: stylianos.tsiaras@epfl.ch

Project
Environmental policy in a new Keynesian Model

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This is the project for Macrofinance (FIN 406). Please upload your project to your group specific Macrofinance Project Submission folder on Moodle; please upload the project report (should not exceed 10 pages) where you answer the questions and seven folders (named question 1, question 2, etc.), each containing the relevant graphs (pdf files) and matlab codes (_run.m , _model.m _ss.m and steady_state.m files). **You need to zip your folders**. If you have troubles uploading your project, you can email it to roy.sarkis@epfl.ch. You should work on this project in groups of 3 people. The project is worth 15% of your final grade.

In 2022 the Intergovernmental Panel on Climate Change (IPCC) issued a worrying report about global warming. This project asks you to study the dynamic behavior of an economy under different environment policy regimes in a New Keynesian model. Higher economic activity improves living conditions. However, economic activity creates pollution. In the short-to medium-term, environmental policy and economic activity are portrayed as being in conflict with one an other. As a consequence, the trade-off between environmental quality and economic efficiency triggers long debates aiming to find the right policy actions. We can expect climate actions to have pervasive effects at macroeconomic level. Since the additional costs of decarbonising an economy involve directly and/or indirectly both households and firms, actions to reduce climate activity should change the optimal conditions of household and firms and their resource constraint.

The model includes a representative agent, firms, the government, the central bank and Nature.

The Representative Agent

The representative worker chooses consumption and labor to maximize their life-time utility. Their utility is given by

$$\max_{C_t,N_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} - \nu \frac{N_t^{1+\frac{1}{\varphi}}}{1+\frac{1}{\varphi}} \right),$$

first: change the model file
second: go to underscore ss file
third: go to steady_state file

where C_t is their consumption, N_t is hours worked, ν is a parameter measuring the disutility from work and φ if the Frisch elasticity of labor supply. The budget constraint of the representative agent is

$$C_t + \frac{b_t}{1+i_t} = (1-\tau_t)w_t N_t + \frac{b_{t-1}}{\Pi_t} + Pr_t, \tag{1}$$

where $w_t \equiv W_t/P_t$ is the real wage, τ_t is a tax on labor income, $b_{t-1} \equiv B_{t-1}/P_{t-1}$ is the quantity of nominal one-period bonds purchased in $t-1$, i_t is the net nominal interest rate, $\Pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate, Pr_t are the profits of the firms, which are rebated back to representative agent.

The Firms

There is a continuum of firms indexed by $i \in [0,1]$. Each firm produces a differentiated good. Firm i produces good i using technology

$$Y_t(i) = (1-\mathcal{I}(M_t))N_t(i)^{1-\alpha} \qquad \alpha \in (0,1). \tag{2}$$

$N_t(i)$ is hours worked in period t. M_t is the amount of pollution, either in the atmosphere, the sea or the soil. $\mathcal{I}(M_t)$ maps the level of pollution to a drop in production. This feedback effect represents adverse effects of pollution on workers' health, which reduces their productivity (e.g. diseases).

Firm i chooses labor in period t to maximize its nominal profits in period t. More precisely,

define profit

$$\max_{N_t(i)} Pr_t \equiv Y_t(i) - w_t N_t(i) - p_Z Z_t(i). \tag{3}$$

where w_t is the real wage. Producing creates pollution. The government issues a permit at price p_Z that firms can buy to pollute. This is an carbon tax. $Z_t(i)$ is the gas emissions (e.g. CO_2) of the firm i.

As you have learned in class, prices are sticky. This is to say that, every period, firms may reset the price of their differentiated good with probability $1-\theta$; this probability is independent of the time elapsed since the last price adjustment. The New Keynesian Phillips curve summarizes the law of motion of inflation in the economy and it is given by

phillips curve

$$\pi_t = \beta E_t \pi_{t+1} + \gamma \hat{mc}_t \tag{4}$$

where $\pi_t \equiv \ln \Pi_t$, $\hat{mc}_t \equiv mc_t - mc = \ln(MC_t/MC)$, where MC_t is the real marginal cost of the firms and MC its steady-state level; moreover

$$\gamma = \frac{(1-\beta\theta)\Theta(1-\theta)}{\theta}, \quad \Theta \equiv \frac{1-\alpha}{1-\alpha+\alpha\epsilon} \leq 1$$

and $\epsilon \geq 0$ is the elasticity of substitution across goods (see Lecture 7).

The Government

The government faces the following budget constraint:

government budget constraint

$$G + \frac{b_{t-1}}{\Pi_t} = \tau_t w_t N_t + \frac{b_t}{1+i_t} + p_Z Z_t \tag{5}$$

where G is fixed government spending, b_{t-1} is the stock of outstanding debt at the beginning of period t, b_t is the debt issued by the government in period t. The government finances spending with debt, labor tax τ_t and by emitting polluting permits $p_Z Z_t$. The labor tax adjusts to clear the government budget.

The Central Bank

The central bank uses an interest-rate rule, typically referred to as a Taylor rule, to decide monetary policy

$$1 + i_t = (1+i)\Pi_t^{\phi_\pi}\left(\frac{Y_t}{Y}\right)^{\phi_y}, \quad \phi_\pi > 1, \phi_y \geq 0, \tag{6}$$

where $y_t \equiv \ln Y_t$. In $\log$ terms, the Taylor rule is

monetary policy

$$i_t = -\ln\beta + \phi_\pi \pi_t + \phi_y (y_t - y),$$

where y is the log steady state of output.

The Nature

The stock of pollution M_t accumulates with current emissions Z_t, current emissions of the rest of the world (ROW) Z_t^*, and decays with factor δ_M.

$$M_t = (1-\delta_M)M_{t-1} + Z_t + Z_t^* \tag{7}$$

The stock of pollution reduces productivity according to

iota polynomial

$$\mathcal{I}(M_t) = \iota_0 + \iota_1 M_t + \iota_2 M_t^2 \tag{8}$$

with $\iota_0 > 0, \iota_1 > 0$ and $\iota_2 > 0$.

Emissions emitted by the firms are proportional to output.

define z

$$Z_t(i) = \psi Y_t(i) \tag{9}$$

Shock Process

The rest of the world gas emissions evolve according to

$$Z_{t+1}^* = \rho Z_t^* + \xi \varepsilon_{t+1},$$

where ε_{t+1} is an i.i.d. zero mean shock with known standard deviation and $\xi > 0$ is a parameter.

Please use the values in Table 1 for the parameters of the model; please use Table 2 for the steady-state values of specific variables of your model. One time period corresponds to one quarter. As you can see, some steady-state variables have "?" as value. You need to find values for these variables as suggested below.

Table 1: Parameter Values

Symbol	Meaning	Value
β	discount factor	0.99
σ	intertemporal substitution	1
φ	Frisch elasticity of labor supply	1
α	curvature production function	0.3
ν	disutility on labor	1
θ	price stickiness	2/3
ϵ	substitution across goods	11
ϕ_π	Taylor rule inflation coeff.	1.5
ϕ_y	Taylor rule output coeff.	0.5/4
G	steady-state government spending	0.4Y
ρ	AR persistence of ROW gas emissions	0.9
δ_M	decay pollution	1 - 0.9979
ϕ_m	Taylor rule emissions coeff.	3
ι_1	productivity loss due to pollution	6/100
ι_2	productivity loss due to pollution	6/100000
ι_0	constant productivity loss	1/1000
ψ	emissions per unit of output	?
ξ	Shock parameter	0.1

Hints for setting up the model

Part of your project grade is setting up and coding the model correctly. You will send us your codes as part of your output for grade.

Table 2: Steady-state Values

Variable	Meaning	Value
i	nominal interest rate	?
$\Pi = 1 + \pi$	inflation	1
b	debt	1
P_Z	Price carbon tax	0.5
M	Total carbon dioxide	?
Z^*	Rest of the world air CO2 emissions	1

1. Government spending equals 0.4 times the steady state value of output Y. It is not a variable, i.e. you do not need to put it in the vector x and xp. You can define it as a parameter. Please remember that you still need to give it a value in your steady state file; since it is a parameter, you do not need to take $\ln$ of it.

2. Bonds are in zero net supply in equilibrium, so we set $b_{steady\ state} = 1$. In your "model.m" file, treat b as a variable for the household (i.e. use it in the budget constraint and get the first order condition with respect to it). Afterwards, since it's zero net supply, we can ignore it, i.e. don't include it in any other equation in your model and don't put it in the state/control vectors (the x and y).

3. You need to write the first order conditions of the household and the firm. In the code, you can use the solutions solved by hand or by the Jacobian. Please derive the first order conditions in the report.

4. Z_t^* and M_t are (state) variables. Make sure you define them as variables in the model file and you place them in the vectors x and xp.

5. The remaining variables are variables (jump variables). Make sure you define them as variables in the model file and you place them in the vectors y and yp.

6. You should set up all equilibrium conditions, and all variables. Depending on how you solve the model, the number of equilibrium conditions and variables might differ.

7. It might be helpful to set up the model step by step.

8. Split up the work.

9. Reach out for help. The exercise sessions are a great opportunity to get feedback. We are going to keep exercise session on Wednesdays, 11h15 to 12h00; please make use of ED. If necessary, we can add an additional hour of exercise session on zoom.

Questions

1. *(10 points)* In this exercise, you will calibrate some parameters and steady state values of the model using real world data.

   (a) *(5 points)* First, set the coefficient ψ measuring emissions per unit of output. Go to "data.worldbank.org" and look for the series "CO2 emissions" expressed in kilograms per 2017 PPP \$ of GDP. Use the value of your given country for 2019 rounded to one decimal for ψ.

(b) *(5 points)* Finally, we calibrate the steady state value of M. Go to "climate.nasa.gov" and look for the page on carbon dioxide. NASA records the total carbon dioxide present in the atmosphere. What is the value in ppm for October 2022? Use this value divided by 10 for the steady state of M.

2. *(30 points)* Set up and code the model correctly. You will send us your codes as part of your output for grading. Please refer to the hint subsection above for suggestions. Please provide us with the steady state of your model (in levels, not in logs) for all variables.

3. *(10 points)* Consider a 20 p.p. increase in Z^* relative to its steady-state level. Please plot the impulse responses of all variables in the model and save the graph as a pdf file named graph1.pdf. We refer to this as the benchmark. Please briefly explain the behavior of all variables.

4. *(10 points)* Please set the price of emitting emissions p_Z to 0.75 and repeat the analysis above. Please plot the impulse responses of all variables in the model and save the graph as a pdf file named graph2.pdf. Please briefly explain why the variables respond differently here relative to the benchmark case.

5. *(10 points)* Please set p_Z back to its benchmark value $p_Z = 0.5$; please increase the government spending to $0.5Y$. Please plot the impulse responses of all variables in the model and save the graph as a pdf file named graph3.pdf. Please briefly explain why the variables respond differently here relative to the benchmark case.

6. *(10 points)* Please set the parameter $\iota_1 = \iota_2 = 0$. What happen in this case compared to the benchmark? Please give a brief intuitive explanation.

7. *(20 points)* Please consider the benchmark case. Suppose the central bank decides to respond to total emissions M_t in deviation of its steady state value. The central bank now uses the rule:

$$i_t = -\ln \beta + \phi_\pi \pi_t + \phi_y (y_t - y) + \phi_m (m_t - m)$$

where m_t is $\ln(M_t)$, m is the steady state value of m_t and ϕ_m is how the central bank respond to deviations from steady state air pollution. Please plot the impulse responses of all variables in the model and save the graph as a pdf file named graph4.pdf. Please briefly explain why the variables respond differently here relative to the benchmark case.