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# THE GROWTH AGENDA AND FINANCING GREEN PROJECTS: AN ENVIRONMENTAL DSGE APPROACH

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**Abstract**

This study aims to develop an environmental dynamic stochastic general equilibrium (E-DSGE) model with heterogeneous production sectors and evaluate possible central bank and fiscal policies towards green and sustainable production. We estimate the model for the Indonesian economy and assess the effects of macroeconomic uncertainty in terms of productivity, monetary, macroprudential, fiscal policy, and financial shocks in a setup that includes policies supporting green firms. We find that aggregate output, consumption, and investment react negatively to a positive monetary policy and government spending shock. Further, we show that emission tax may dampen the contraction of green output due to contractionary monetary and fiscal policy. The effect of green financing subsidy, however, looks trivial

**Keywords:** DSGE model; Bayesian estimation; Monetary policy; Fiscal policy; Environ- mental policy

JEL Classifications: E32, E50, Q58,

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# 1. Introduction

Growth is desired as long as it is economical. When uneconomic growth happens, it costs us more than the worth of the consumed goods. In other words, uneconomic growth occurs when production increases come at the expense of resources and well-being that is worth more than the commodities made (Daly (1972); Daly (1991); Meadows, Randers, and Meadows (2005)). Increasing consumption beyond the balance point of marginal utility (level of satisfaction ofthe population's needs and wants) and marginal disutility (labor, loss of leisure, depletion of resources, exposure to pollution, and congestion) makes growth becomes uneconomic. Unfortunately, most of the time, we are not aware of the truest worth of the consumed goods. This makes most financial policy and business decisions are made without measuring the environmental- related disutility. This paper aims to show how the agenda of growth and support for green projects interact and contribute to providing the policymakers and academics in assessing the pro-green policy instruments. Developing an environmental DSGE model that is calibrated to the Indonesian economy, this research is imperative as Indonesia is a high climate-vulnerable developing country.

# 2. Literature Review

The unsustainable consumption and production practices bring about the vicious circle of ris- ing world population (demand), intensification production strategy and environmental damage (Rishanty et al., (2020); Rishanty, (2021)). As the environmental damage and climate change intensify, climate- related financial risks are more detectable (Dafermos, Nikolaidi, and Galanis (2017)). They are the transition risks and the physical risks. The former are risks that have to do with the re-valuation of carbon-intensive assets due to shocks related to the transition to a low-carbon economy. At the same time, the latter are risks that are linked to the economic damages of climate-related events.

Monetary transmission channels are likely to become increasingly exposed to climate-relatedrisks, both transition and physical risks, through expectation channels and credit channels, which may affect the value of assets available to banks to participate in central bank monetary policy operations. The physical and transition risks may lead to higher risk aversion and uncertainty, thereby changing preferences and risk premia. When climate change is translated into such risks, it may lead to assets becoming" stranded," i.e., losing value due to unanticipatedchanges in expected cash flows. All of these may hit the firms' solvency, and profitability hence generating rising NPLs. Changes in preferences, risk premia may also change the fundamentalof supply and demand in goods and labor markets, and as a result, steer the global value chains and commodity markets to change. Such transmissions are in feedback loops and amplification (NGFS (2020)).

Some central banks have implemented policies regarding the financial instability due to climate change issues, such as the Bank of Lebanon with reducing reserve requirement ratios of commercial banks which support projects under energy savings, Bank of Bangladesh with providing additional liquidity to commercial banks lending to the green sector, Reserve Bankof India with the implementation of a minimum proportion of bank lending to flow the green financing, and Bank of Japan with subsidized priority loans to financial institutions which give loan program to green sectors (Punzi (2018)).

Climate change is likely to have severe effects on the stability of the financial system (Agli- etta and Espagne (2016); Batten, Sowerbutts, and Tanaka (2016); Scott, van Huizen, and Jung (2017)). The physical and transition risks may directly affect the individual business and households (i.e., property damage, stranded assets, changing demand and costs due to policy changes, loss of income, etc.), as well as the macroeconomy (i.e., prices, productivity, labor market, socioeconomic and international trade pattern changes, capital depreciation and in- creased investment, fluctuations in fiscal space, output, interest rates, and exchange rates, etc.). Climate change effects on the stability of the financial system arise from the rising credit risk (rising default risk, collateral depreciation), market risk (climate-induced asset price change), underwriting risk (increased insured losses, insurance gap), operational risk (supply chain dis- ruption), liquidity risk (cash is king / increased demand for liquidity, refinancing risk). Further, there are economic and financial system feedback effects, and also, climate and economic feed-back effects (micro and macro-economic conditions may as well affect the transition risks to change (policy, technology, and consumer preferences), and then may affect the physical risks to increase (NGFS (2020))

Punzi (2018) finds that there is s a positive financial shock to green firms that can boost production and credit for the green sector, while a positive technology shock and a looser monetary policy lead to a short output on impact, but in the longer-term green firms experience losses. Punzi (2018) also finds that only differentiated requirements can help to sustain green financing. Daly (1972) and Daly (1991) finds that climate change can affect the financial stability through the increase of the rate of default of corporate loans, portfolio reallocation by households that can cause the decline of the price of corporate bonds, and climate-induced financial instability might adversely affect credit expansion. Meanwhile, Dafermos, Nikolaidi, and Galanis (2018) also finds that green corporate QE program could reduce the risks of financial instability by climate change. Still, green QE is not by itself capable of preventing the reduction of temperature. It needs the implementation of green fiscal policies and other green financing policies.

The unsustainable environment itself can generate imbalances in the real economy and affect price stability, then consequently harm production (Punzi (2018)). Climate change can also negatively affect the aggregate demand through the increased risk perception of the entrepreneurs due to the high likelihood of climate-change catastrophes that may destroy their assets and more household savings for climate change-related precautionary reasons that lead to less consumption. These then would translate into a lower economic growth (Dafermos et al. (2017)).

Climate change strategy implies a shift to low-carbon investments to adopt technology to lower greenhouse gas emissions. However, green energy sources are expensive and could lead to losses for companies using renewable resources (Punzi (2018)). Two major barriers associated with green energy projects are a lower rate of return compared to fossil fuel projects and a higher risk of investment compared to fossil fuel projects (Yoshino and Taghizadeh-Hesary (2018)). In general, difficulty in accessing external financing is the main obstacle for producers. These financial constraints are worse for the green sector, as the private sector is reluctant to invest due to environmental risk. In this context, green financing will play a central role in allocating resources to sustainable investments. Academics and policymakers have suggested policies to reduce emissions through price instruments (i.e., carbon tax) or quantity instruments (i.e., cap and trade), and these policies can affect the increase of higher cost of production of green sectors (Punzi (2018)). Because of the associated risk and Basel capital requirements, many banks are not interested in lending to the green energy sector. The specific investment in green sectors is essential to develop a green transformation in the production sector, and green financing will play a central role in allocating resources to sustainable investments (Punzi (2018)). Hence, it is important to assess supporting policies to secure the flow of funds and growth in the green sector.

This study aims to develop an environmental dynamic stochastic general equilibrium (E- DSGE) model with heterogeneous production sectors and evaluate possible central bank and fiscal policies to support green financing for sustainable growth. Referring to previous research, Vasilev (2018) has developed an environmental real business cycle (E-RBC) model for Bulgaria and studied the transmission mechanism of a carbon tax and the use of government spending on abatement costs. Vasilev (2018) finds that the model performance increases by imposing specific environmental regulations, such as by-product reduction of pollution. Xu, Xu, and Lu (2016) developed an E-DSGE model calibrated to the People's Republic of China (PRC) for theperiod between 1978 and 2014. They find that the introduction of environmental policies leads to economic loss, and taxes might encourage firms to participate in emissions-cutting activities. The closest paper related to this paper is (Punzi (2018)). However, Punzi (2018) did not provide the simulation of impacts of macroprudential policies available.

In this study, we build a two-sector production environmental New Keynesian DSGE model with a banking sector to assess the effect of various policies aimed at reducing emission. Unlike Annicchiarico and Dio (2015) and Benmir and Roman (2020), who built calibrated model, we estimate our model using the Bayesian approach for the Indonesian economy. We find a similar result to Annicchiarico and Dio (2015), positive monetary and government spending shocks generate contractions on consumption and investment. In our model, however, government spending also crowds out production. The increase of labor hours due to negative wealth effects on households cannot compensate for the large decline in investment, thus capital stock.Emission tax and green financing subsidies reduce the adverse response of green production, but the effe2cts are trivial.

This study is the first to develop and estimate an environmental dynamic stochastic general equilibrium (E-DSGE) model that includes macroeconomic uncertainty of productivity, monetary, macroprudential, fiscal policy, and financial shocks with the best of our knowledge goal of green and sustainable growth. This research aims to the literature gap in studying the relevance and feasibility of implementing" green" macroprudential monetary policies in Indonesia.

## 3. The Model

The model extend a basic New Keynesian DSGE (NK-DSGE) model with environmental variables a banking sector. It closely follows Heutel (2012), Annicchiarico and Dio (2015), Punzi (2018), Benmir and Roman (2020), and Gertler and Karadi (2011) There are two types of firms in the economy–i.e., green and non-green polluting firms. The polluting firms produces carbon which is released into that atmosphere. For these firms, total factor productivity is endogenous and as the stock of carbon in the atmosphere increases, the productivity falls.

To model the impact of green financing to the economy, we add banking sector to the model economy. In each period $t$, a fraction $1 - f$ household in the interval [0, 1] are workers and the rest of them are bankers. Each banker continues being a banker in the next period with probability $\chi$. Bankers manage a bank and give back the profit to the household. Banks do not own deposits and different households are exposed to idiosyncratic risk.

Government in this model economy raises revenue from emission tax levied to non-green firms and subsidizes green financing by paying a fraction of interest the firms should pay to banks.

### 3.1. Households

#### 3.1.1 Intertemporal Problem

Intertemporal problem In each period $t$, a representative household chooses how much to consume, supply labor to green and non-green intermediate good firms, purchase bonds, anddeposit fund in the bank to maximizes the expected lifetime discounted utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \Big( \frac{c_t^{1-\sigma}-1}{1-\sigma} - \psi_G \frac{h_{G,t}^{1+\varphi}}{1+\varphi} - \psi_N \frac{h_{N,t}^{1+\varphi}}{1+\varphi} \Big)$$

subject to a budget constraint

$$c_t + \frac{D_t}{p_t} = r_{t-1} \frac{D_{t-1}}{p_t} + w_{G,t} h_{G,t} + w_{N,t} h_{N,t} + \Pi_t + \Pi_{B,t} - \tau_t$$

where $\Pi_t$ *and* $\Pi_{B,t}$ are the profit from final goods firm and bank. $D_t$ denotes the sum of public bonds $D_{P,t}$ and bank deposit $D_{\mathrm{F},t}$, which pay a nominal interest rate $r_t$. Let $d_t = \frac{D_t}{p_t}$, $d_{P,t} = \frac{D_{P,t}}{p_t}$ and $d_{P,t} = \frac{D_{F,t}}{p_t}$ , the first order conditions with respect to $\{c_t, h_{G,t}, h_{N,t}, d_t\}$ are

$$\begin{aligned} c_t^{-\sigma} &= \lambda \\ \psi h_{G,t}^{\varphi} &= \lambda_t w_{G,t} \\ \psi h_{N,t}^{\varphi} &= \lambda_t w_{N,t} \\ \lambda_t &= \beta \mathbb{E}_t \Big( \lambda_{t+1} \frac{r_t}{\pi_{t+1}} \Big). \end{aligned}$$

#### 3.1.2 Intertemporal Problem

Intertemporal problem Households' consumption bundle includes green and non-green products, $\{c_G, c_N\}$ respectively,

$$c_t = \Big( \omega_G^{\frac{1}{\eta_G}} c_{G,t}^{\frac{\eta_G-1}{\eta_G}} + (1-\omega_G)^{\frac{1}{\eta_G}} c_{N,t}^{\frac{\eta_G-1}{\eta_G}} \Big)^{\frac{\eta_G}{\eta_G-1}}$$

where $\eta_G$ and $\omega_G$ are the elasticity substitution between the goods and the share of green goodsin the consumer's consumption bundle.

The consumer choose the allocation of her consumption expenditure between the two goods,

$$\max_{\{c_{G,t},c_{N,t}\}} \left(\omega_G^{\frac{1}{\eta_G}} c_{G,t}^{\frac{\eta_G-1}{\eta_G}} + (1-\omega_G)^{\frac{1}{\eta_G}} c_{N,t}^{\frac{\eta_G-1}{\eta_G}}\right)^{\frac{\eta_G}{\eta_G-1}}$$

subject to

$$p_{G,t}c_{G,t} + p_{N,t}c_{N,t} = \mathcal{E}_t$$

where $p_{G,t}$ and $p_{N,t}$ denote the price of green and non-green goods, respectively, and $E_t$ is a given level of expenditure. Taking the first order conditions and plug $c_{N,t}$ back to the consumptionbundle equation, we get the demand for each type of goods

$$c_{G,t} = \omega_G\left(\frac{p_{G,t}}{p_t}\right)^{-\eta_G} c_t$$
$$c_{N,t} = (1-\omega_G)\left(\frac{p_{N,t}}{p_t}\right)^{-\eta_G} c_t.$$

Plugging back the two equations to the expenditure equation, we get the aggregate level of price

$$p_t = \left(\omega_G G, t^{1-\eta_G} + (1-\omega_G)p_{N,t}^{1-\eta_G}\right)^{\frac{1}{1-\eta_G}}.$$

Note that the consumer also faces the same problem with investment. The demand for eachgoods for investment purposes and the aggregate level of price of investment goods are given by

$$i_{G,t} = \omega_G^I\left(\frac{p_{G,t}}{p_t}\right)^{-\eta_G^I} i_t$$
$$i_{N,t} = (1-\omega_G^I)\left(\frac{p_{N,t}}{p_t}\right)^{-\eta_G^I} i_t$$
$$p_t^I = \left(\omega_G^I p_{G,t}^{1-\eta_G^I} + (1-\omega_G^I)p_{N,t}^{1-\eta_G}\right)^{\frac{1}{1-\eta_G^I}}$$

## 4. Banks

Let $b_{G,t}(j)$, $b_{N,t}(j)$, denote bank $j$'s loan to green and non-green firms and $n_t(j)$ denote the bank's net worth, the bank's balance sheet is

$$b_{G,t}(j) + b_{N,t}(j) = n_t(j) + d_{F,t}(j).$$

The net worth evolves following a law of motion

$$n_t(j) = \left(r_{G,t}^B - \frac{r_{t-1}}{\pi_t}\right)b_{G,t-1}(j) + \left(r_{N,t}^B - \frac{r_{t-1}}{\pi_t}\right)b_{N,t-1}(j) + \frac{r_{t-1}}{\pi_t}n_{t-1}(j)$$

where $r_{G,t}^B$ and $r_{N,t}^B$ are the interest rate on bank's asset for green and non-green firms, respectively.

Bank $j$ only operates if and only if the following condition is met

$$\mathbb{E}_t\left(\beta^i \Delta_{t,t+1+i}\left(r_{t+1+i}^B - \frac{r_{t+i}}{\pi_{t+1+i}}\right)\right) \geq 0.$$

The bank maximizes the expected terminal wealth

$$V(n_t(j)) = \max \mathrm{E}_t\Big(\sum_{i=0}^{\infty}(1-\chi)\chi^i\beta^{i+1}\Delta_{t,t+1+i}n_{t,t+1+i}(j)\Big)$$

subject to

$$n_{t+1}(j) = \Big(r^B_{t+1} - \frac{r_t}{\pi_{t+1}}b_{F,t}(j) + \frac{r_t}{\pi_{t+1}}n_t(j)\Big).$$

Using a recursive formulation, we can re-write the problem as followed

$$V(n_t(j)) = \max \mathrm{E}_t\Big((1-\chi)\beta\frac{\lambda_{t+1}}{\lambda_t}n_{t+1}(j) + \chi\beta\frac{\lambda_{t+1}}{\lambda_t}V_{t+1}(n_{t+1}(j))\Big)$$

subject to

$$n_{t+1}(j) = \Big(r^B_{t+1} - \frac{r_t}{\pi_{t+1}}b_{F,t}(j) + \frac{r_t}{\pi_{t+1}}n_t(j)\Big).$$

A banker $j$ continues the activity with a probability $\chi$ and banks can divert $\theta_B$ fraction of the assets. Thus, savers are willing to lend if and only is the following constraint is satisfied

$$V_t(n_t(j)) \geq \theta_B(r^B_{G,t}b_{G,t}(j) + r^B_{N,t}b_{N,t}(j)).$$

Find the solution to this problem requires us to guess a solution

$$V_t(n_t(j)) = v_{k,t}(b_{G,t}(j) + b_{N,t}(j)) + v_{n,t}n_t(j)$$

where $v_{k,t}$ and $v_{n,t}$ denote the marginal value of investing one additional unit in loans and the marginal value of holding one unit of net worth. Let $lev_t(j)$ be the leverage of bank $j$

$$lev_t(j) \equiv \frac{b_{G,t}(j) + b_{N,t}(j)}{n_t(j)}.$$

Considering an equilibrium with a binding constraint,

$$lev_t(j) = \frac{v_{n,t}}{\theta - v_{k,t}}.$$

Note that, it turns out that the leverage does not depend on bank-specific variable. To get theaggregate demand for banks' asset, add the loans across individual demands

$$b_{G,t}(j) + b_{N,t}(j) = lev_t n_t.$$

Re-write the guess using the above equation

$$V_t(n_t(j)) = (v_{k,t}lev_t + v_{n,t})n_t(j).$$

Use the guessed solution, we get

$$V_t(j) = \mathrm{E}_t\Big(\beta\frac{\lambda_{t+1}}{\lambda_t}v_{t+1}n_{t+1}(j)\Big)$$

where $v_t \equiv (1-X) + X(v_{k,t}lev_t + v_{n,t})$. Let $b_{G,t}(j) + b_{N,t}(j) = b_{F,t}$ and then substitute the law of motion of net worth to the above equation

$$V_t(j) = \mathrm{E}_t\Big(\beta\frac{\lambda_{t+1}}{\lambda_t}v_{t+1}\Big(\Big(r^B_{t+1} - \frac{r_t}{\pi_{t+1}}\Big)(b_{F,t}(j)) + \frac{r_t}{\pi_{t+1}}n_t(j)\Big)\Big)$$

which imply

$$v_{k,t} = \mathrm{E}_t\Big(\beta\frac{\lambda_{t+1}}{\lambda_t}v_{t+1}\Big(\Big(r^B_{t+1} - \frac{r_t}{\pi_{t+1}}\Big)\Big)$$
$$v_{n,t} = \mathrm{E}_t\Big(\beta\frac{\lambda_{t+1}}{\lambda_t}v_{t+1}\Big(\frac{r_t}{r_{t+1}}\Big)\Big).$$

Thus, the aggregate leverage is

$$lev_t = \frac{\mathrm{E}_t\Big(\beta\frac{\lambda_{t+1}}{\lambda_t}v_{t+1}\Big(\frac{r_t}{r_{t+1}}\Big)\Big)}{\mathrm{E}_t\Big(\beta\frac{\lambda_{t+1}}{\lambda_t}v_{t+1}\Big(\Big(r^B_{t+1} - \frac{r_t}{\pi_{t+1}}\Big)\Big)}.$$

Using the previous expression for $v_t$,

$$v_t = (1-\chi) + \chi\beta\mathrm{E}_t\Big(\beta\frac{\lambda_{t+1}}{\lambda_t}v_{t+1}\Big(\Big(r^B_{t+1} - \frac{r_t}{\pi_{t+1}}\Big)lev_t + \frac{r_t}{r_{t+1}}\Big).$$

New young bankers and old bankers split the total net worth

$$n_t = n_{O,t} + n_{Y,t}.$$

Because old bankers survive from period $t-1$ to $t$ with a probability $\chi$,

$$n_{O,t} = \chi\Big(\Big(r^B_t - \frac{r_{t-1}}{\pi_t}\Big)b_{F,t-1} + \frac{r_{t-1}}{\pi_t}n_{t-1}\Big).$$

The household transfers $\frac{\iota}{1-X}$ fraction of existing bankers' assets to the new bankers so,

$$n_{Y,t} = \iota b_{F,t-1}.$$

The expression for the net worth's evolution is

$$n_t = \chi\Big(\Big(\Big(r^B_{G,t} - \frac{r_{t-1}}{\pi_t}\Big)b_{G,t-1} + \frac{r_{t-1}}{\pi_t}n_{t-1}\Big) + \Big(r^B_{N,t} - \frac{r_{t-1}}{\pi_t}\Big)b_{N,t-1} + \frac{r_{t-1}}{\pi_t}n_{t-1}\Big)\Big) - \dots$$
$$\Big(\chi\frac{r_{t-1}}{\pi_t} + \frac{\iota}{1-\chi}\Big)n_{t-1}.$$

We get the aggregate deposit by aggregating over individual bank's balance sheet

$$d_{F,t} = b_{G,t}(j) + b_{N,t}(j) - n_t.$$

## 5. Firms

The economy produces two types of goods, green and non-green final goods. These goods are intermediate goods produced by firms in a monopolistically competitive market. They produce output using labor and capital. Non-green pollution firms emit carbon into the atmosphereand the total factor productivity for both firms is decreasing in the stock of carbon in the atmosphere. A higher production by non-green firms increase bad emissions which in turn suppress the productivity frontier on the economy–for example, due to global warming caused by a high level of carbon the atmosphere.

### 5.1 Final good firms

Production consists of two sectors–i.e., green and non-green, indexed by $i \in [G, N]$. A representative firm $j \in [0, 1]$ produces a final good $y_{i,t}(j)$ in a perfectly competitive market using a specific type of capital and labor. A final good firm bundles the two types of goods into a final good using the following production function

$$y_t = \left(\omega_G^{\frac{1}{\theta_G}} y_{G,t}^{\frac{\theta_G-1}{\theta_G}} + (1-\omega_G)^{\frac{1}{\theta_G}} y_{N,t}^{\frac{\theta_G-1}{\theta_G}}\right)^{\frac{\theta_G}{\theta_G-1}}$$

where $\theta_G > 1$ denotes the elasticity of substitution between the goods and $\omega_G$ is the weight ofgreen goods in the final good.

The final firms chooses how much they produce to maximize profit or,

$$\max_{\{y_t(j)\}} \Pi_t = p_t y_t - \omega_G \int_0^1 p_{G,t}(j) y_{G,t}(j) \mathrm{d}j - (1-\omega_G) \int_0^1 p_{N,t}(j) y_{N,t}(j) \mathrm{d}j$$

subject to the two types of intermediate goods,

$$y_{i,t} = \int_0^1 \left((y_{i,t}(j))^{\frac{\eta_i-1}{\eta_i}}\right)^{\frac{\eta_i}{\eta_i-1}} \mathrm{d}i.$$

The first-order condition for the problem is

$$y_{i,t}(j) = \left(\frac{p_{i,t}(j)}{p_{i,t}}\right)^{-\eta_i} \left(\frac{p_{i,t}}{p_t}\right)^{-\theta_G}$$

The prices of each sector $i \in [G, N]$ and the aggregate goods are given by

$$p_{i,t} = \left(\int_0^1 (p_{i,t}(j))^{1-\eta_i} \mathrm{d}j\right)^{\frac{1}{1-\eta_i}}$$

$$p_t = (\omega_G p_{G,t}^{1-\theta_G} + (1-\omega_G) p_{N,t}^{1-\theta_G})^{\frac{1}{1-\theta_G}}.$$

### 5.2 Non-green intermediate firms

A firm indexed by $i \in [0, 1]$ uses the following production function to produce good $i$

$$y_{N,t}(i) = a_{N,t}(s_{N,t}^K k_{N,t-1}(i))^\alpha (h_{N,t}(i))^{1-\alpha}$$

where $s_{N,t}^K$ captures an exogenous variation in non-green capital

$$\ln(s_{N,t}^K) = \rho_{S_N} \ln(s_{N,t-1}^K) + \epsilon_{SN,t},\ \epsilon_{SN,t} \sim \mathcal{N}(0, \sigma_{SN,t}^2)$$

and $a_{N,t}$ denotes the total factor productivity, which is decreasing in the stock of carbon in theatmosphere $x_t$,

$$a_{N,t} = (1 - a_3(a_0 + a_1 x_t + a_2 x_t^2)) a_t$$

where $a_t$ denotes an exogenous total factor productivity which follows an AR(1) process

$$\ln(a_t) = (1-\rho_A)\ln(a) + \rho_A \ln(a_{t-1}) + \epsilon_{A,t},\ \epsilon_{A,t} \sim \mathcal{N}(0, \sigma_A^2).$$

Total domestic emission $e_t = \int_0^1 di$ and world emission $e^W$ causes the buildup of atmospheric
carbon

$$x_t = \rho_X x_{t-1} + e_t + e^W.$$

For the domestic polluting firms, emissions are increasing in the production

$$e_t(i) = (1 - m_t(i))\gamma_1 (y_{N,t}(i))^{1-\gamma_2}$$

where $m_t$ are the level of emission abated by the firm $i$ and the abatement cost is proportional to it production

$$\nu_t(i) = y_{N,t}(i)\theta_1 (m_t(i))^{\theta_2}.$$

The firm $i$ is operating in a monopolistically competitive market. Thus, it can set its own price subject to the demand for final goods. Following Rotemberg (1982) setup, the firm has to pay a quadratic adjustment cost $ac_t(i)$ in nominal terms, and the firm adjust the prices with respect to the steady-state level of inflation $\pi_N$ . This firm also pays tax $\tau_t^E$ for each unit of emissions. Furthermore, the firm also faces a financing constraint–it has to finance capital expenditure by borrowing $f_{N,t}$ from banks or the government

$$f_{N,t} = q_{N,t} k_{N,t}(i).$$

This firm purchase capital from the capital producers which buy undepreciated capital from the intermediate firms. To maximize the profit, the firm chooses $\{p_{N,t}(i), h_{N,t}(i), y_{N,t}(i), k_{t-1}(i), e_t(i), m_t(i)\}$:

$$\begin{aligned}
\mathrm{E}_0\Big(\sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0}\Big(\Big(\frac{p_{N,t}(i)}{p_{N,t}}\Big)^{1-\epsilon_N} y_{N,t}(i) - w_{N,t}h_{N,t}(i) - r_N^K k_{N,t-1} - \dots \\
\tau_t^E e_t + y_{N,t}(i)\theta_1(m_t(i))^{\theta_2} - \frac{\kappa_N^P}{2}\Big(\frac{p_{N,t}(i)}{p_{N,t-1}(i)} - \pi_N\Big)^2 y_{N,t}\Big) + \dots \\
mc_{N,t}\Big(\Big(a_{N,t}(s_{N,t}^K k_{N,t-1}(i))^{\alpha}(h_{N,t}(i))^{1-\alpha}\Big) y_{N,t}\frac{p_{N,t}(i)}{p_{N,t}}\Big)^{-\epsilon_N}\Big)\Big)
\end{aligned}$$

subject to

$$\begin{aligned}
y_{N,t}(i) &= y_{N,t}\Big(\frac{p_{N,t}(i)}{p_{N,t}}\Big)^{-\epsilon_N} \\
y_{N,t}(i) &= a_{N,t}(k_{N,t-1}(i))^{\alpha}(h_{N,t}(i))^{1-\alpha} \\
e_t(i) &= (1 - m_t(i))\gamma_1(y_{N,t}(i))^{1-\gamma_2}.
\end{aligned}$$

where the rental rate of capital is

$$r_{N,t}^K \equiv r_{N,t}^B q_{N,t-1} - (1-\delta) q_{N,t} s_{N,t}^K.$$

The first-order conditions with respect to $\{k_{N,t}, h_{N,t}, m_t, p_{N,t}\}$ are

$$r^K_{N,t} = mc_{N,t}(i)\alpha a_{N,t}(k_{N,t-1}(i))^{\alpha-1}(h_{N,t})^{1-\alpha}$$

$$w_{N,t} = mc_{N,t}(i)(1-\alpha)a_{N,t}(k_{N,t-1}(i))^{\alpha}(h_{N,t})^{-\alpha}$$

$$\tau^E_t y^{-\gamma_2}_{N,t} = \theta_1\theta_2(m_t(i))^{\theta_2-1}$$

$$(1-\epsilon_N)\Big(\frac{p_{N,t}(i)}{p_{N,t}}\Big)^{-\epsilon_N}\frac{y_{N,t}}{p_{N,t}} + \epsilon_N(1-\gamma_2)\tau^E_t\gamma_1\frac{y^{1-\gamma_2}_{N,t}}{p_{N,t}}\Big(\frac{p_{N,t}(i)}{p_{N,t}}\Big)^{-\epsilon_N(1-\gamma_2-1)}(1-m_t(i)) + \dots$$
$$\epsilon_N\frac{y_{N,t}}{p_{N,t}}\Big(\frac{p_{N,t}(i)}{p_{N,t}}\Big)^{-\epsilon_N-1}\theta_1(m_t(i))^{\theta_2} + \epsilon_N mc_{N,t}(i)\Big(\frac{p_{N,t}(i)}{p_{N,t}}\Big)^{-\epsilon_N-1} - \dots$$
$$\frac{\kappa^P_N}{p_{N,t-1}(i)}\Big(\frac{p_{N,t}(i)}{p_{N,t-1}(i)} - \pi_N\Big)y_{N,t} + \dots$$
$$\kappa^P_N\beta\mathbb{E}_t\Big(\frac{\lambda_{t+1}}{\lambda_t}\frac{p_{N,t+1}(i)}{(p_{N,t}(i))^2}\Big(\frac{p_{N,t+1}(i)}{p_{N,t}(i)} - \pi_N\Big)^2 y_{N,t+1}\Big).$$

Assuming a symmetric equilibrium at which firms choose the similar input, price, and output,the above conditions can be written as

$$r^K_{N,t} = mc_t\alpha\frac{y_{N,t}}{k_{N,t-1}}$$

$$w_{N,t} = mc_t(1-\alpha)\frac{y_{N,t}}{h_{N,t}}$$

$$m_t = \Big(\frac{\tau^E_t\gamma_1}{\theta_1\theta_2}y^{-\gamma_2}_{N,t}\Big)^{\frac{1}{\theta_2-1}}$$

$$\pi_{N,t}(\pi_{N,t}-\pi_N) = \beta\mathbb{E}_t\Big(\frac{\lambda_{t+1}}{\lambda_t}\pi_{N,t+1}(\pi_{N,t+1}-\pi_N)^2\frac{y_{N,t+1}}{y_{N,t}}\Big) + \dots$$
$$\frac{\epsilon_N}{\kappa^P_N}\Big((mc_{N,t} + (1-\gamma_2)\gamma_1\tau^E_t y^{-\gamma_2}_{N,t}(1-m_t) + \theta_1 m^{\theta_2}_t) - \frac{\epsilon_N - 1}{\epsilon_N}\Big)$$

The last equation depicts a non-linear environmental Philips curve. When $\tau^E = \infty \rightarrow m_t = 0$
and the curve is the standard Philips curve. Note that when the tax equals to zero, there isno incentive for non-green firms to abate emission–thus, no abatement, or $m_t = 0$. Using the marginal product of capital and labor, we can derive the real profits for non-green firms

$$J^I_{N,t} = y_{N,t}\big(1 - mc_{N,t} - \tau^E_t(1-m_t)\gamma_1 y^{-\gamma_2}_{N,t} - \theta_1 m^{\theta_2}_t - \frac{\kappa^P_N}{2}(\pi_{N,t}-\pi_N)^2\big).$$

### 5.3 Green intermediate firms

Green firms face a similar financing constraint and profit maximization problem. However, these firms do not pollute the environment when producing output. Thus, the total factor productivity for green firms is

$$a_{G,t} = (1 - a_3 a_0)a_t.$$

The profit maximization problem yields the following

$$r^K_{G,t} = mc_{G,t}\alpha \frac{y_{G,t}}{k_{G,t-1}}$$

$$w_{G,t} = mc_{G,t}(1-\alpha)\frac{y_{G,t}}{h_{G,t}}$$

$$\pi_{G,t}(\pi_{G,t}-\pi_G) = \beta \mathbb{E}_t\Big(\frac{\lambda_{t+1}}{\lambda_t}\pi_{G,t+1}(\pi_{G,t+1}-\pi_G)^2\frac{y_{G,t+1}}{y_{G,t}}\Big) + \frac{\epsilon_G}{\kappa^P_G}\Big(mc_{G,t}-\frac{\epsilon_G-1}{\epsilon_G}\Big)$$

$$J^I_{G,t} = y_{G,t}\big(1-mc_{G,t}-\frac{\kappa^P_G}{2}(\pi_{G,t}-\pi_G)^2\big).$$

In this model, we assume that the government subsidize green firms' operation by paying a fraction of interest the firms have to pay to banks. This setup means that the rental rate of capital for these firms is given by

$$r^K_{G,t} \equiv (1-\tau_G)r^B_{G,t}q_{G,t-1} - (1-\delta)q_{G,t}s^K_{G,t}$$

where $\tau_G > 0$ is the subsidy on green firms' loans.

## 5.4 Capital producers

These firms purchase the final goods and undepreciated capital from specific, green or non-green, intermediate firms to produce a specific type of capital. For a firm that produces green capital, the problem is following

$$\max_{\{i_{G,t}\}} \mathrm{E}_t \sum_{t=0}^{\infty} \beta^t \frac{\lambda_t}{\lambda_0}\Big(q_{G,t}\Big(1-\frac{\kappa_I}{2}\Big(\frac{i_{G,t}}{i_{G,t-1}}-1\Big)^2\Big)-1\Big).$$

The first-order condition is

$$q_{G,t}\Big(1-\frac{\kappa_I}{2}\Big(\frac{i_{G,t}}{i_{G,t-1}}-1\Big)^2\Big) - \kappa_1\frac{i_{G,t}}{i_{G,t-1}}\Big(\frac{i_{G,t}}{i_{G,t-1}}-1\Big)$$
$$\beta\mathrm{E}_t\Big(\frac{\lambda_{t+1}}{\lambda_t}q_{G,t+1}\Big(\frac{i_{G,t+1}}{i_{G,t}}\Big)^2\kappa_I\Big(\frac{i_{G,t+1}}{i_{G,t}}-1\Big)\Big) = 1.$$

Similarly, the first order condition for the profit maximization for non-green capital produces is

$$q_{N,t}\Big(1-\frac{\kappa_I}{2}\Big(\frac{i_{N,t}}{i_{N,t-1}}-1\Big)^2\Big) - \kappa_1\frac{i_{N,t}}{i_{N,t-1}}\Big(\frac{i_{N,t}}{i_{N,t-1}}-1\Big)$$
$$\beta\mathrm{E}_t\Big(\frac{\lambda_{t+1}}{\lambda_t}q_{N,t+1}\Big(\frac{i_{N,t+1}}{i_{N,t}}\Big)^2\kappa_I\Big(\frac{i_{N,t+1}}{i_{N,t}}-1\Big)\Big) = 1.$$

Profit of both firms are

$$\Pi^K_{G,t} = q_{G,t}k_{G,t} - (1-\delta)s^K_{G,t}q_{G,t}k_{G,t-1} - i_{G,t}$$

$$\Pi^K_{N,t} = q_{N,t}k_{N,t} - (1-\delta)s^K_{N,t}q_{N,t}k_{N,t-1} - i_{N,t}.$$

## 5.5 Policies

### 5.5.1 Monetary Policy

The central bank targets the nominal interest rate according the Taylorrule

$$\frac{r_t}{r} = \left(\frac{r_{t-1}}{r}\right)^{\rho_R} \left(\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{y_t}{y}\right)^{\phi_Y}\right)^{1-\rho_R} \exp(\epsilon_t^R)$$

where $\epsilon_t^R \sim N(0, \sigma_R^2)$ denotes the monetary policy shock.

### 5.5.2 Fiscal Policy

The government finances its consumption and the subsidy to green firms

$\tau_G$ by levying lumpsum tax to household and emission tax to non-green firms

$$g_t + \tau_G f_{G,t} = \tau_t + \tau_t^E e_t$$

where $g_t$ follows an AR(1) process

$$\ln(g_t) = (1 - \rho_G) \ln(g) + \rho_G \ln(g_{t-1}) + \epsilon_{G,t}, \ \epsilon_{G,t} \sim \mathcal{N}(0, \sigma_G^2)$$

and $\epsilon_{G,t}$ denotes the public consumption shock. In this setup, there are four different environ-mental regimes (Annicchiarico and Dio (2015)):

1. No policy. This implies that $\tau_t^E = 0$ and $m_t = 0$
2. Cap. In this regime, the government is fixing the emission $e_t = e$ which can be interpreted as the government selling emission permits in which the price is determined endogenously.
3. Target. The government sells emission permits and target the emission $e_t = \omega_E y_t$.
4. Tax. The government levy a constant tax on emissions.

## 5.6 Market Clearing and aggregation

Using the demand function of green and non-green goods, we get the market clearing condition for the goods are

$$y_{G,t} = c_{G,t} + i_{G,t} + g_{G,t} + \frac{\kappa_G^P}{2}(\pi_{G,t} - \pi_G) y_{G,t}$$

$$y_{N,t} = c_{N,t} + i_{N,t} + g_{N,t} + \frac{\kappa_N^P}{2}(\pi_{N,t} - \pi_G) y_{N,t} + y_{N,t}\theta_1 m_t^{\theta_2}$$

The market clearing for capital and labor are

$$k_t = k_{N,t} + k_{G,t}$$

$$h_t = h_{N,t} + h_{G,t}.$$

The aggregate resource constraint is obtained by consolidating household budget constraint, firms' profit ($J_t = J_{G,t}^F + J_{N,t}^F + J_{G,t}^I + J_{N,t}^I$), and government budget constraint

$$c_t + i_t + g_t + y_{N,t}\theta_1 m_t^{\theta_2} + \frac{\kappa_N^P}{2}(\pi_{N,t} - \pi_N) = y_t$$

where

$$y_t = \frac{p_{G,t}y_{G,t} + p_{N,t}y_{N,t}}{p_t}.$$

## 6. Estimation

We use the Bayesian method to estimate the model. The procedure starts from a prior distribution describing available information prior to observing the data used to estimate the model. Then, the data is used to update the prior to the posterior distribution of the model's parametersvia Bayes' theorem

### 6.1. Data and calibrated parameters

To estimate the model, we use quarterly Indonesiandata from 2010Q1-2019Q4 and match four variables: real GDP per capita, CPI, the short-run interest rate, and credit per capita. First, all data are seasonally adjusted using STLdecomposition. Then we take out the trend from all data by using the Hodrick-Prescott filter.

Some parameters are calibrated or kept constant during the estimation. Most of those parameters are related to the steady-state values of the observed data and calibrated to match their sample mean. For example, we set the government spending to GDP ratio to 0.18. Since we do not have environmental data available, all environmental parameters for example, $\theta_1, \theta_2, \gamma_1, \gamma_2, \delta_M, X$ *are* taken from Annicchiarico and Dio (2015) and Gertler and Karadi (2011). Table 1 reports the calibrated parameters and the corresponding steady-state values of some key variables.

Table 1 Calibrated Parameters

| Parameter | Description | Value |
|---|---|---|
| $\epsilon_N = \epsilon_G$ | Elasticity substitution between of intermediate goods | 6.0000 |
| $\chi$ | Survival rate of bankers | 0.9720 |
| $G$ | Gov't spending to GDP ratio | 0.1800 |
| $y_G/y_N$ | Ratio of green to non-green output in steady state | 0.0002 |
| $\delta_M$ | Pollution decay | 0.9979 |
| $\gamma_1$ | Shifter in emission function | 0.4500 |
| $\gamma_2$ | Concavity in emission function | 0.0000 |
| $\vartheta_1$ | Shifter in abatement function | 0.1850 |
| $\vartheta_2$ | Convexity in abatement function | 2.8000 |

| | | |
|---|---|---|
| $a_0$ | Constant in damage function | 0.0013 |
| $a_1$ | 1st order coefficient term in damage function | 0.0000 |
| $a_2$ | 2nd order coefficient term in damage function | 0.0000 |

Source : Author

### 6.2. Prior distributions of the estimated parameters

The remaining parameters and the exogenous shock processes are estimated. The location of prior distribution correspond to that in Annicchiarico and Dio (2015) and Benmir and Roman (2020). The beta distribution is used for all parameters bounded between 0 and 1. For those assumed to be positive, we use inverse gamma distribution. For unbounded parameters, the normal distribution is used. Table 2 shows the exact location, the prior uncertainty, and the prior distribution for each estimated parameter.

Table 2 Prior and Posterior Distribution of Structural Parameters

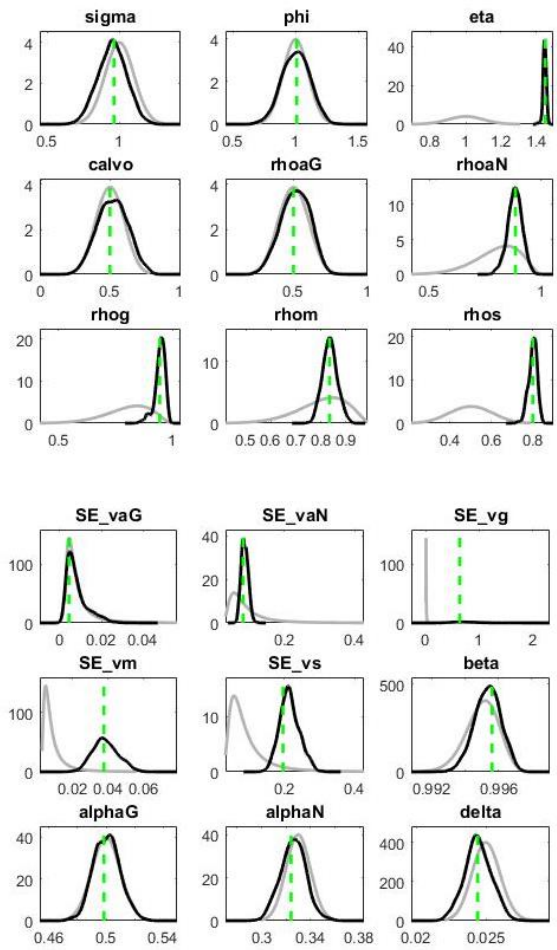
| | Distribution | Mean | Std. dev | Mean | 5% | 95% |
|---|---|---|---|---|---|---|
| [illegible] | Beta | 0.9950 | 0.0010 | 0.9953 | 0.9941 | 0.9967 |
| $G$ | Beta | 0.5000 | 0.0100 | 0.5004 | 0.4855 | 0.5150 |
| $N$ | Beta | 0.3300 | 0.0100 | 0.3258 | 0.3071 | 0.3406 |
| [illegible] | Beta | 0.0250 | 0.0010 | 0.0244 | 0.0228 | 0.0260 |
| [illegible] | Normal | 1.0000 | 0.1000 | 0.9492 | 0.7893 | 1.1013 |
| [illegible] | Normal | 1.0000 | 0.1000 | 1.0018 | 0.8327 | 1.1825 |
| [illegible] | Normal | 1.0000 | 0.1000 | 1.4469 | 1.4343 | 1.4622 |
| $G$ | Beta | 0.5000 | 0.1000 | 0.5124 | 0.3494 | 0.6973 |
| $N$ | Beta | 0.8000 | 0.1000 | 0.8826 | 0.8329 | 0.9385 |
| $R$ | Beta | 0.8000 | 0.1000 | 0.8350 | 0.7855 | 0.8825 |
| $S$ | Beta | 0.5000 | 0.1000 | 0.7996 | 0.7630 | 0.8294 |
| $\pi$ | Normal | 3 | 0.1000 | 3.2212 | 3.0725 | 3.3965 |
| $\pi$ | Normal | 0.1 | 0.0050 | 0.0823 | 0.0727 | 0.0913 |

| | | | | | | |
|---|---|---|---|---|---|---|
| *AG* | Inv. Gamma | 0.01000 | 0.1 | 0.0082 | 0.0025 | 0.0160 |
| *AN* | Inv. Gamma | 0.0100 | 0.1 | 0.0879 | 0.0727 | 0.1040 |
| *G* | Inv. Gamma | 0.0100 | 0.1 | 0.7647 | 0.3214 | 1.1353 |
| *R* | Inv. Gamma | 0.0100 | 0.1 | 0.0384 | 0.0280 | 0.0510 |
| *S* | Inv. Gamma | 0.1000 | 0.1 | 0.2149 | 0.1664 | 0.2572 |

Source: Author

### 6.3. Posterior distributions and model fit

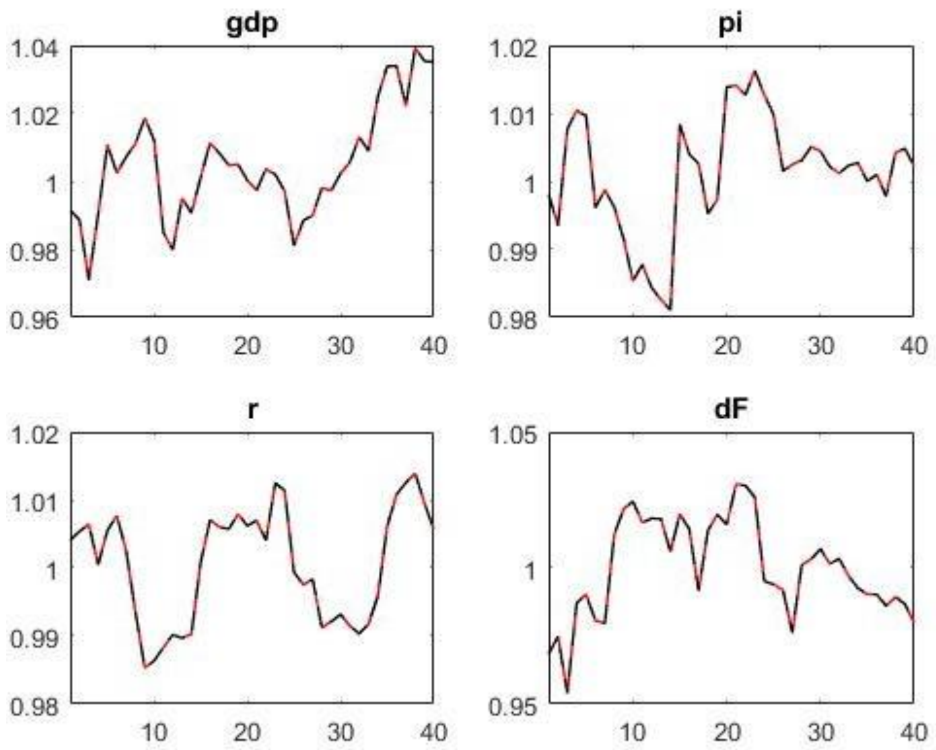
The posterior mean and distribution of the estimated parameters are shown in the last three columns of Table 2, and the graph is shown in Figure A.1. Overall, the estimated parameters compare quite well tothe estimate in the literature of a small open economy. Unfortunately, we cannot compare the estimated parameters to Annicchiarico and Dio (2015) and Benmir and Roman (2020) because they only calibrated their model.




Source: Author

Figure 1 : Posterior Distributions

In Figure 2, we report the data and the model's estimates of the observed variable computed using the posterior mode of the estimated parameters. We achieve a satisfactory in-sample fit of the model. All observed variables grow just as fast in the model compared to the observed data. However, to further confirm the model fit, we need to conduct a posterior predictive analysis by comparing the vector autocovariance functions in the model and the data. We leave this exercise for future improvement.




Source: Author

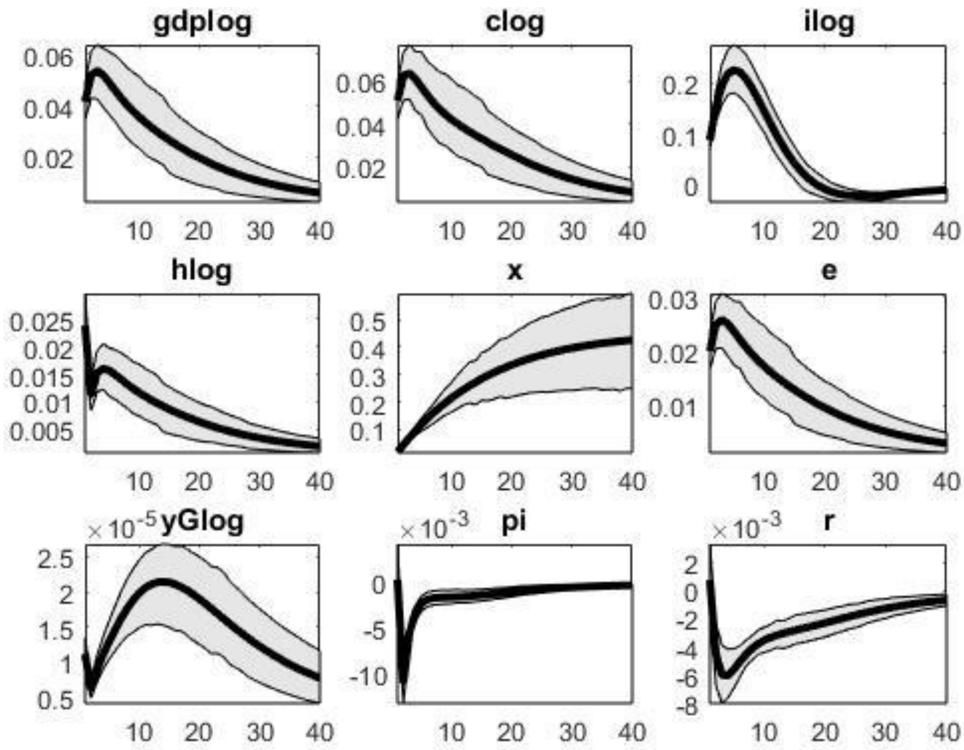
Figure 2 : Historical data (black solid line) and smoothed values from the model (red dashed line).

## 7. Result and Discussion

### 7.1. Impulse response functions (IRF)

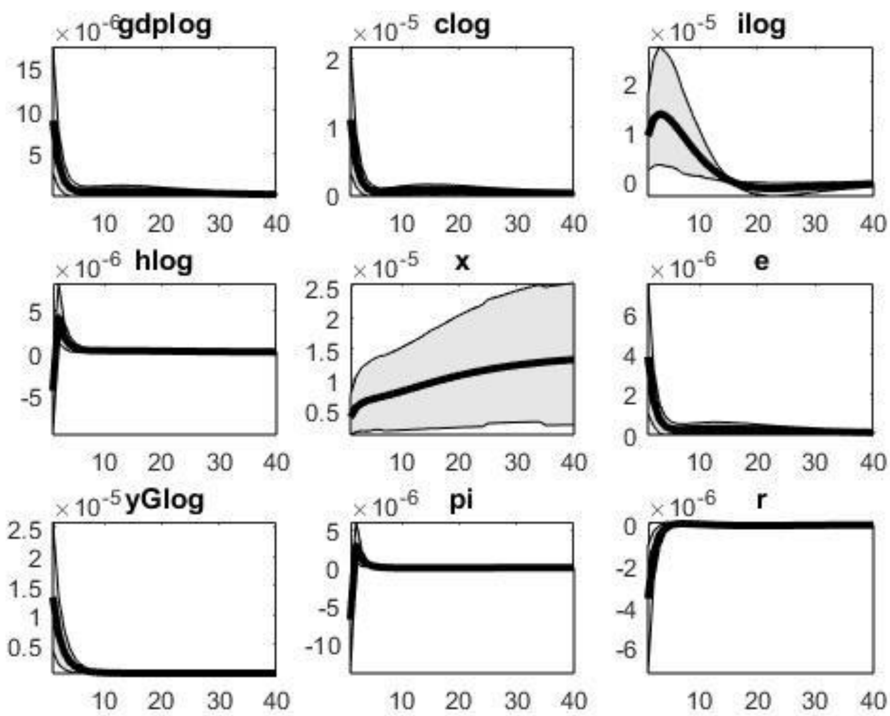
#### 7.1.1. Impulse response functions of technology shock

Figure 3 displays the impulse response functions (median and the 5th and 95th percentiles) of one standard deviation increase in non-green technology shock $\epsilon_{AN,t}$. As expected, output, consumption, investment, labor hours increase. Consequently, emission and the stock of carbon in the atmosphere. The in- crease in emission and the stock of carbon in the atmosphere are both large and persistent, and green production decrease slightly. In contrast, one standard deviation increase in non-green technology shock $\epsilon_{AG,t}$ affects the economy in a rather non-meaningful way. The rise in out- put, consumption, investment, labor hours are all minimal. Figure 4 shows that the green production also increases but is negligible.




Source: Author

Figure 3 : Response of one standard deviation of non-green technology shocks, percentage deviation from steady-state.

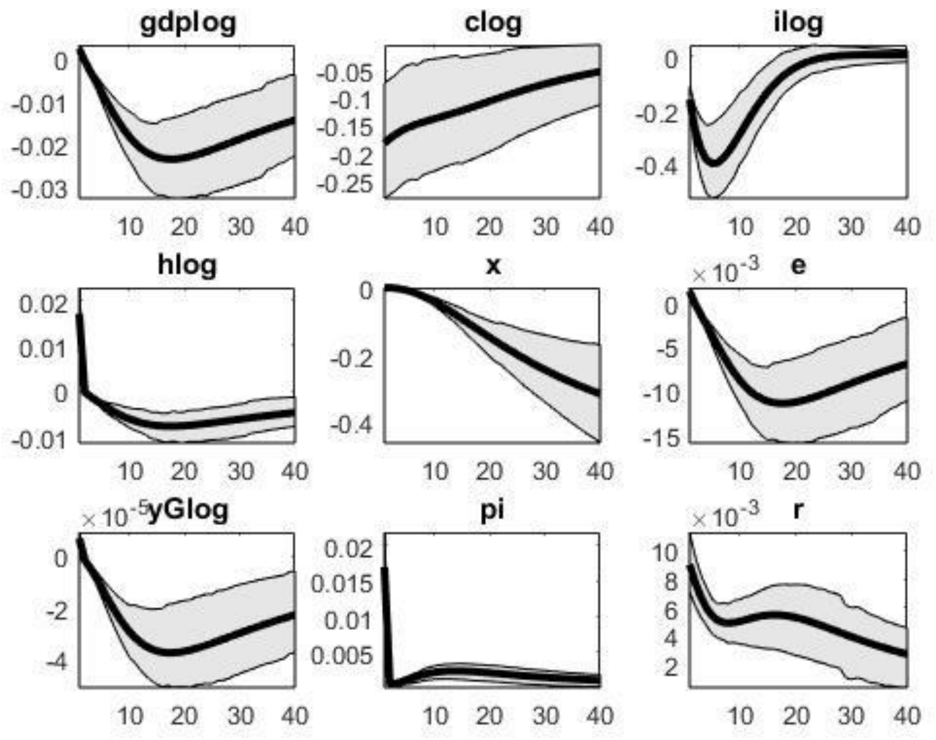



Source: Author

Figure 4 : Response of one standard deviation of green technology shocks, percentage deviation from steady-state.

#### 7.1.2. Impulse response functions of government spending shock

Figure 5 illustrates the impulse response functions of one standard deviation of government spending shock. Following the shock, output, consumption, and investment fall–government spending shock crowds out private consumption and investment. Labor hours increase because an increase in government consumption means there are fewer resources available for private use. Households feel poorer, and they work harder to offset the fall in consumption. In a standard model, the increase in hours boosts output on impact. Thus, the overall expansionary effect on output will be higher. However, unlike Annicchiarico and Dio (2015) we find that output slightly contracts since the fall of investment (thus the capital stock) is higher than the labor hours. The contractionary effect positively affects the environment–emission and stock of carbon in the atmosphere fall, but green production also declines.




Source: Author

Figure 5 : Response of one standard deviation of government spending shocks, percentage deviation from steady-state.

#### 7.1.3. Impulse response functions monetary policy shock

A monetary policy shock generates a contractionary effect on consumption and investment. In response to the tightening of monetary policy, those variables fall sharply. Labor and output fall subsequently. As a result, emissions and the stock of carbon in the atmosphere fall. Green production falls slightly underthe baseline of no tax policy and no financing subsidy to green firms.

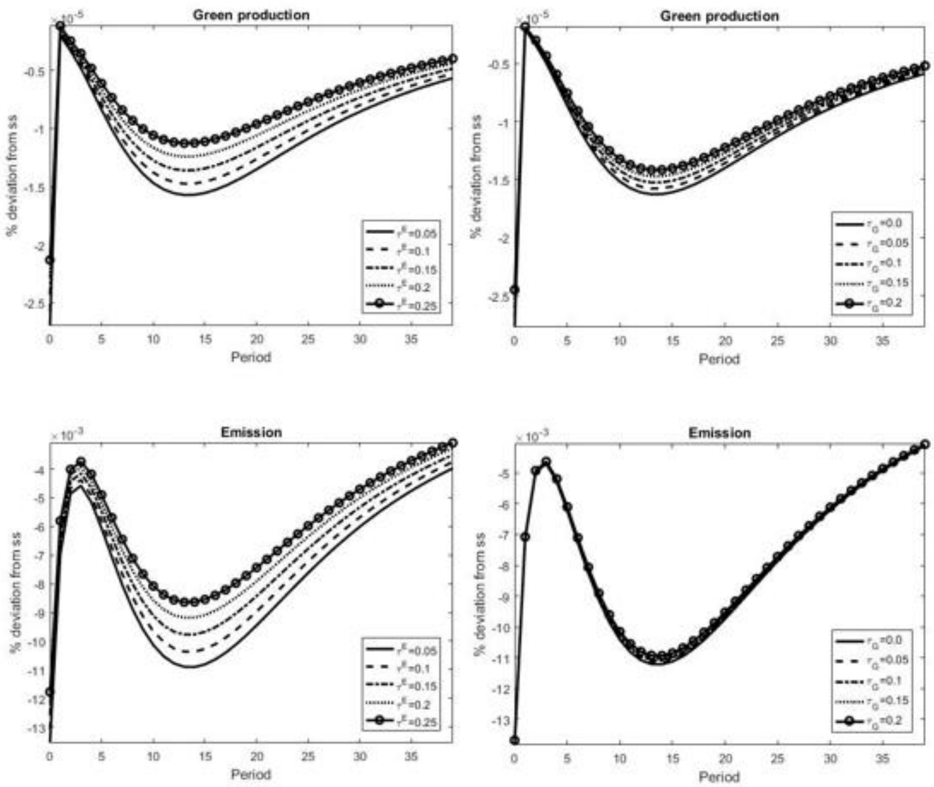
### 7.2. Policy simulations

In this section, we simulate the effect of different levels of emission tax and green financing subsidy. We use the model estimated using the Bayesian approach as the baseline and obtain the green production and emission responses for those policies. We set arbitrary values for the emission tax $\tau^E = \{0.05, 0.1, 0.15, 0.2, 0.25\}$ and the subsidy $\tau_G = \{0, 0.05, 0.1, 0.15, 0.2\}$ and compare the responses to monetary and fiscal policy shocks.

#### 7.2.1. Policy simulations for monetary policy shocks

In Figure 8, we plot the responses of green production and emission to monetary policy shock. As shown in the baseline model IRF, the shock generates an increase in the real interest rate, which depresses output and aggregate demand. The economy slightly recovers when the nominal interest rate falls, but the contractions in output and consumption linger due to persistent negative effects on investment. Because output falls, emission declines. Increasing emission tax lowers the emission further. However, the policy pushes down green production even more.

Handing out financing subsidies to green firms provides the same positive effect on emission. But the range of the responses is a lot narrower–different subsidy levels do not affect the response of emission by much. This pattern is visible in the response of green production aswell. Subsidizing green firms' financing cannot dampen the green output contraction due to monetary policy shock.

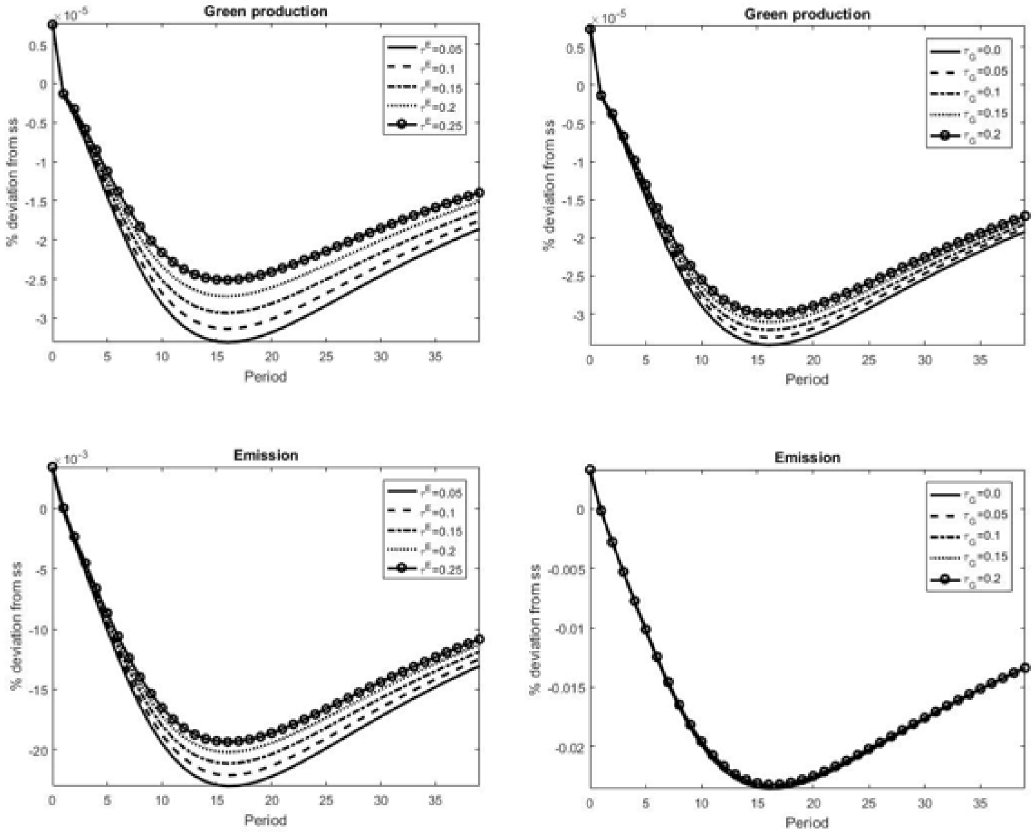



Source: 1 Author

Figure 8 : Responses of green production and emission to monetary policy shocks for various level of emission tax (left panel) and green financing subsidy (right panel).

### 7.2.2. Policy simulations for monetary policy shocks

Figure 9 displays the responses of green production and emission to government spending shock. The contractionary effect on output translates into lower emissions. Green production, however, also declines relative to its steady- state value. Analogous to the responses to a monetary policy shock, higher emission tax and green financing subsidy result in smaller contractions—albeit trivial.




Source: Author

Figure 9 : Responses of green production and emission to government spending shock for various level of emission tax (left panel) and green financing subsidy (right panel).

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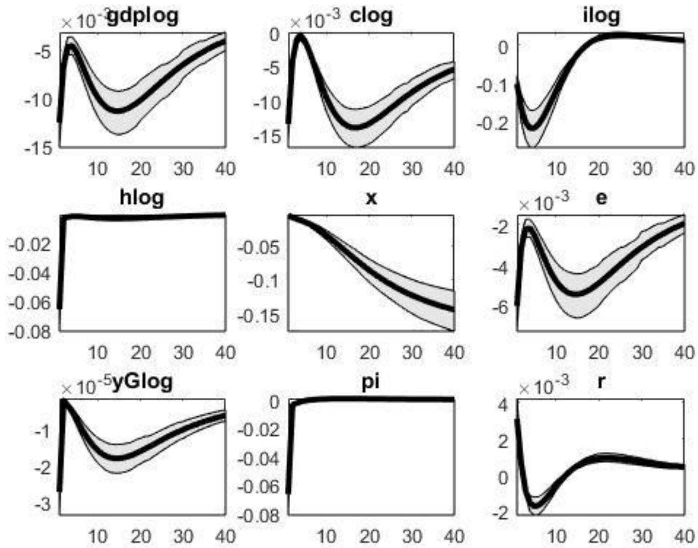
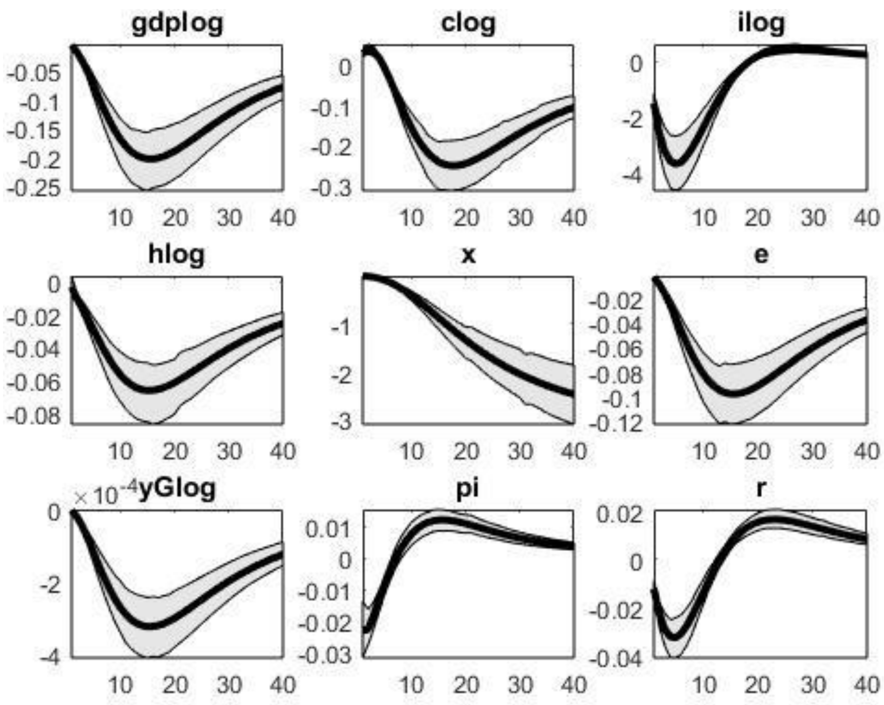
Appendix




Source: Author

Figure 6 : Response of one standard deviation of monetary policy shocks, percentage deviation from steady-state




Source: Author

Figure 7 : Response of one standard deviation of shocks in the value of capital, percentage deviation from steady-state.