# Oil Prices and Inequality

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**Abstract**

This paper provides a unified framework to understand the effect of oil price changes on the dynamics of consumption, income and wealth inequality. Using data on macroeconomic aggregates, oil prices, and inequality metrics, we first employ a structural vector autoregressive model to show that an increase in oil prices leads to a persistent rise in income and wealth inequality. To understand these dynamics, we then solve an incomplete market model with aggregate oil price shocks, and calibrate the model to the US data. We find that when oil serves as both consumption goods and production input, positive oil price shocks increase inequality through the relative price changes between labor and capital. While the initial rise in inequality is primarily driven by changes in relative prices, the gradual recovery of capital returns and capital stock explains why inequality remains persistently elevated.

Keywords: oil price shocks, inequality, heterogeneous agent

JEL Classification Numbers: D31, E10, Q43

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# 1 Introduction

Energy stands as a vital driver of economic activity in the United States, and is recognized as a critical industry due to its enabling role across various economic sectors. Consequently, fluctuations in oil prices can significantly influence aggregate economic dynamics. It is widely acknowledged that oil price shocks lead to stagflation, characterized by higher inflation and lower aggregate consumption, investment, and output (Hamilton (2008) and Kilian (2009)). However, the distributional effect of oil price shocks remains inadequately explored.

This paper addresses this question by studying the dynamic responses of inequality to oil price changes since the Great Moderation period, both empirically and theoretically.[1] To offer insights into the nexus between oil prices and income and wealth distribution, we illustrate their relationship in Figure 1 based on the impulse response functions derived from the Structural Vector Auto-regressive (SVAR) analysis using annual data on aggregate variables, oil prices, and various inequality metrics in the U.S. economy from 1985 to 2019.[2] Specifically, we conduct simulations of the economy following a positive shock to oil prices, assessing its dynamic impacts on income and wealth inequality, measured as the gap between the top 1% and bottom 50%. The results show significant inequality spikes over ten years post-shock.

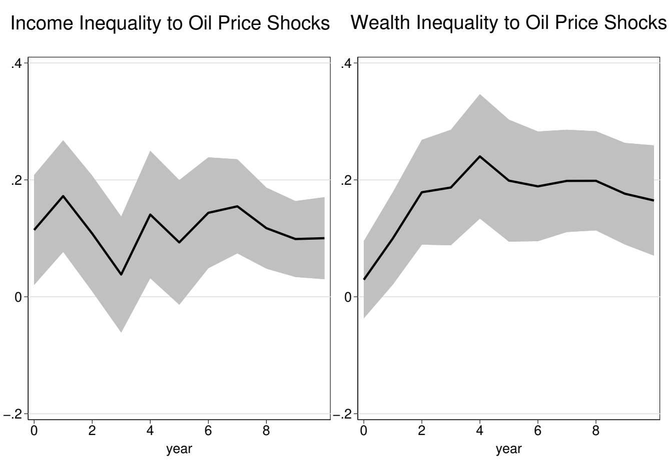


Figure 1: Oil Price Shocks and Inequality (Vertical axis unit is percent. The gray area shows 68% confidence interval.)

This raises the question: What underlying factors could drive this positive relationship between oil prices and inequality? To answer this question, we build and solve a continuous-time

[1] We focus on this period when macroeconomic volatility began to significantly decline, documented by Stock and Watson (2003) and Bernanke (2004), among others. In addition, as stated in Blanchard and Riggi (2013), the effects of oil price shocks on the aggregate economy have become significantly different during this period than in 1970s.

[2] The detail of the analysis is presented in Section 3.

heterogeneous agent model with a one time aggregate oil price shock where oil serves as both a consumption good and a production input. This framework enables us to examine the dynamic impact of oil price fluctuations across the entire spectrum of consumption, income, and wealth distribution within a general equilibrium context. The model is calibrated to the U.S. economy from 1985 to 2019. Following a one-time positive oil price shock, our simulation outcomes indicate a contraction in aggregate economic activities, including output, consumption, and investment, while the general price level increases, which aligns with the literature that typically views oil price shocks as a negative supply-side shock. Moreover, the Gini coefficients of consumption, income, and wealth exhibit an increase, with the intuition summarized below.

In the short run, the increase in income inequality is primarily driven by the changes in the relative price of capital and labor. Since wealthier households tend to earn more income from interest rates than wages, changes in income inequality become a balancing act between capital and labor income. Following a positive oil price shock, demand for energy inputs diminishes, leading to a decrease in the marginal product of both capital and labor, thus exerting downward pressure on wages and interest rates. However, the reduction in interest rates is less pronounced because there is now less total output available for consumption and saving, resulting in a decreased capital supply. Operating at a lower level of capital supply mitigates some of the downward pressure on interest rates, which then raises income inequality. Second, as income inequality increases, so does consumption inequality. Finally, wealth inequality rises because the increase in income inequality outweighs the rise in consumption inequality. If one fixes the level of income, the rise of consumption inequality could suggest that the poor are now saving more in response to a positive oil price shock, potentially narrowing the wealth distribution. However, quantitatively, this impact is dominated by the more pronounced increase in income inequality.

Over the medium run, the increase of income and wealth inequality persists, which is attributed to the different rates of recovery between capital demand and capital supply. In the aftermath of an oil price shock, capital demand quickly recovers, while the recovery of capital supply is much slower. This is because the accumulation of capital supply takes time. When capital demand outpaces capital supply recovery, it causes the interest rate to overshoot beyond the equilibrium level for a while before returning to its baseline equilibrium level, thereby further amplifying income and wealth inequality.

To gain deeper insights into the various factors influencing the dynamics of inequality, we proceed to undertake several counterfactual analyses atop the baseline model. First, by reducing oil intensity used in production, lowering the share of oil consumption among households, and increasing the elasticity of substitution between consumption of oil goods and final goods, we find that the aggregate economy contracts less compared to the baseline results. Furthermore, the adverse impact of oil price shocks on consumption, income and wealth inequality is mitigated as well. Second, we explore the asymmetric impact of oil price shock by comparing the impulse response functions of positive vs. negative oil price changes on the economy. We find that the impact of oil price shock is highly asymmetric, with the negative oil price shock (i.e.: a reduction in oil prices) affecting both the aggregate and the distributional variables proportionately more. Further, we compare two economies with different borrowing constraints and find that inequality is less affected by higher oil prices when a no-borrowing constraint is imposed. Finally, we explore the policy effect of the recent widely debated carbon tax proposal on rising oil prices and inequality. We find that a carbon tax can reduce aggregate demand but can cause a short-term consumption spike if the revenue is distributed as transfers, increasing income and wealth inequality.

Several recent studies are closely related to our work. For instance, Oni (2024) examines the distributional impact of such shocks by comparing steady states outcomes across different oil price levels. Pieroni (2023) and Auclert, Monnery, Rognlie, and Straub (2023) build and solve heterogeneous agent models with nominal rigidity, focusing on short-term fluctuations in aggregate demand through nominal channels. In contrast, our study focuses on the real effects of distributional variables and their long-term dynamics. Another major distinction lies in our incorporation of capital in production, which is essential in understanding how oil prices influence inequality through capital accumulation.

The subsequent sections of this paper are structured as follows: Relevant literature is outlined in Section 2. In Section 3, a structural vector autoregressive analysis examines the empirical relationships of oil prices, macro aggregates and distributional variables. Section 4 presents an incomplete market model featuring oil price shocks. The general equilibrium conditions are presented in Section 5, characterizing both the steady state and transition dynamics of the economy. Section 6 solves the model numerically, presenting the impulse response functions of aggregate and distributional variables to oil price shocks. In Section 7, we conduct several counterfactual analyses atop of the baseline model. A fiscal policy experiment featuring carbon tax is presented in Section 7.5. The paper concludes in Section 8. The appendix contains data descriptions for the SVAR analysis.

## 2 Literature review

The paper attempts to bridge the gap between two seemingly unrelated pieces of literature. The first is recent literature that focuses on the macroeconomic dynamics of income and wealth inequality. It is widely acknowledged that both income and wealth inequality has been rising significantly worldwide since the 1980s (Piketty (2014)). While the topic of wealth inequality was primarily studied within the field of development economics, it has recently gained attention among macroeconomists (Ahn, Kaplan, Moll, Winberry, and Wolf (2018)). Some focuses on taxes and technology (Kaymak and Poschke (2016)), globalization (Azzimonti, De Francisco, and Quadrini (2014)), entrepreneurship (Jones and Kim (2018)), automation (Moll, Rachel, and Restrepo (2022)), some focus on monetary policy (Kaplan, Moll, and Violante (2018)), others examine the heterogeneous return to wealth (Fagereng, Guiso, Malacrino, and Pistaferri (2020)), etc. We fill in the gap of the literature by exploring the relationship between oil price shocks and inequality.

The second literature it relates to is the macroeconomics of energy. It has been documented in the literature that oil price changes serve as one of the most important supply-side disturbances that can generate fluctuations in the aggregate economy. Traditional macroeconomic theory suggests that oil price shocks lead to stagflation, featuring higher price level and lower aggregate demand ( Hamilton (1983), Rotemberg and Woodford (1996), Hamilton (2003), Barsky and Kilian (2004), Kilian (2008), Edelstein and Kilian (2009), Herrera, Karaki, and Rangaraju (2019), Koirala and Ma (2020)),).

Few studies have focused on the distributional impact of oil prices. Most existing work focuses on empirical analysis. They either examines the natural resource curse (Brunnschweiler and Bulte (2008), Parcero and Papyrakis (2016), Sebri and Dachraoui (2021)), as well as how oil price shocks affect income inequality (Parcero and Papyrakis (2016), Kim and Lin (2018), and Edmond, Chisadza, Matthew, and Rangan (2021)). Bettarelli, Estefania-Flores, Furceri, Loungani, and Pizzuto (2023) recently explores how energy price inflation affects consumption inequality. We contribute to the existing literature by presenting a structured theoretical framework along with empirical analysis, highlighting diverse responses to typical oil price shocks.

# 3 Empirical Evidence

In this section, we present our empirical evidence from a structural vector autoregressive analysis (SVAR) by exploring the relationship between oil prices and aggregate and distributional variables between 1985 and 2019. In particular, we are interested in a baseline SVAR model with the following variables:

$$\begin{bmatrix} \Delta\log(\textit{oil prices}) \\ \Delta\log(\textit{consumption}) \\ \Delta\log(\textit{real GDP}) \\ \Delta\log(\textit{employment}) \\ \Delta\log(\textit{wage}) \\ \textit{federal funds rate} \\ \Delta\log(CPI) \\ \textit{saving rate} \\ \textit{inequality} \end{bmatrix}$$

We employ oil price data and macroeconomic data sourced from the FRED databases, along with inequality data obtained from the top income database Saez and Zucman (2016). The baseline model operates at an annual frequency with 2 lags, utilizing log differences for non-stationary variables such as oil prices, consumption, GDP, employment, wage, and CPI.[3] The income and wealth inequality metrics are formulated as the differences in income/wealth share between the top 1% group and the bottom 50% group. The model is identified by Cholesky decomposition, i.e., we order oil prices as the first variable, which implies that oil price shocks can contemporaneously

[3]The specifics of the variable definitions are elaborated in the appendix A.

affect all the other variables, whereas other variables can only influence oil prices with a lag.

The estimation results are shown in Figure 2 and Figure 3. A positive oil price shock leads to declines in overall consumption and savings, whereas real GDP slightly rises in the first period while subsequently falling below the steady state. At the same time, the wage rate and employment decrease, while the price level rises. The impact on income and wealth inequality is notable and long-lasting, with the peak effects reaching 20 basis points above the baseline level.

As a robustness check, we calculate impulse response functions using monthly data on income and wealth inequality from 1985 to 2019, along with other aggregate variables, from a local projection approach with 12 lags.[4] Figures 4 and 5 display the aggregate and distributional effects of a positive oil price shock, indicating that both income and wealth inequality rise following an increase in oil prices. This result echos the baseline findings, reassuring that higher oil prices can lead to a non-trivial and persistent movement on inequality. To comprehend the outcome of these aggregate and distributional dynamics, we need a model.

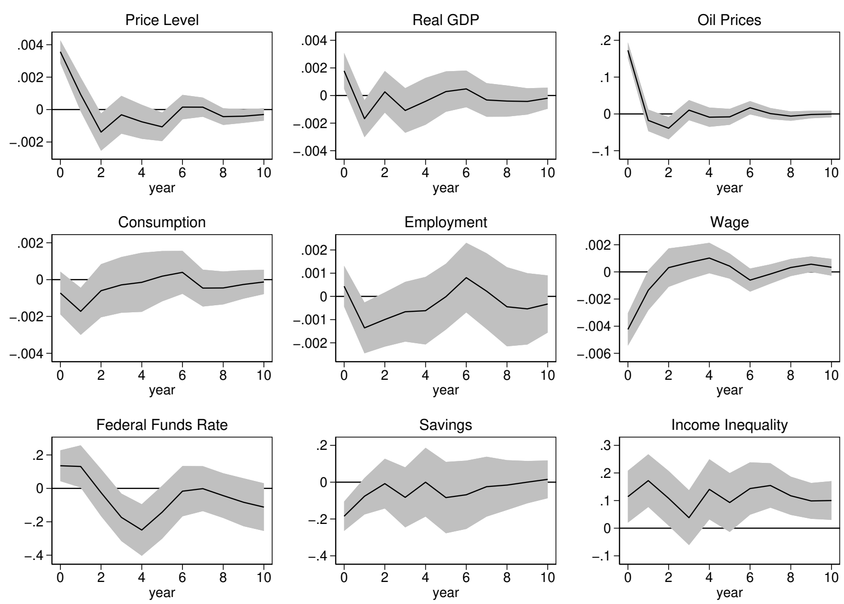


Figure 2: The Impact of Oil Price Changes on Income Inequality. (The gray area shows 68% confidence interval.)

[4]Monthly data on income and wealth inequality are obtained from https://realtimeinequality.org/, which is constructed based on the methodology proposed in Blanchet, Saez, and Zucman (2022). Income/wealth inequality are defined as the differences in income/wealth share between the top 10% group and the bottom 50% group.

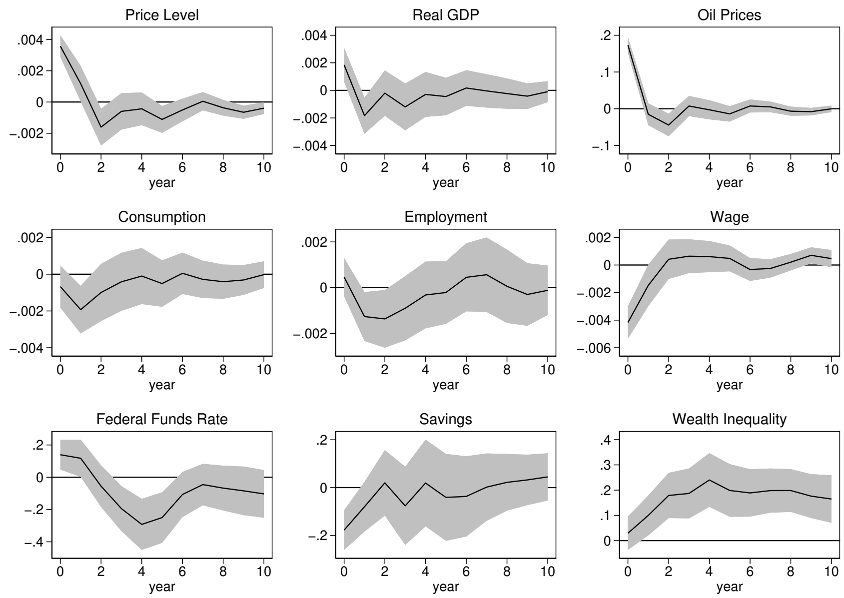


Figure 3: The Impact of Oil Price Changes on Wealth Inequality. (The gray area shows 68% confidence interval.)

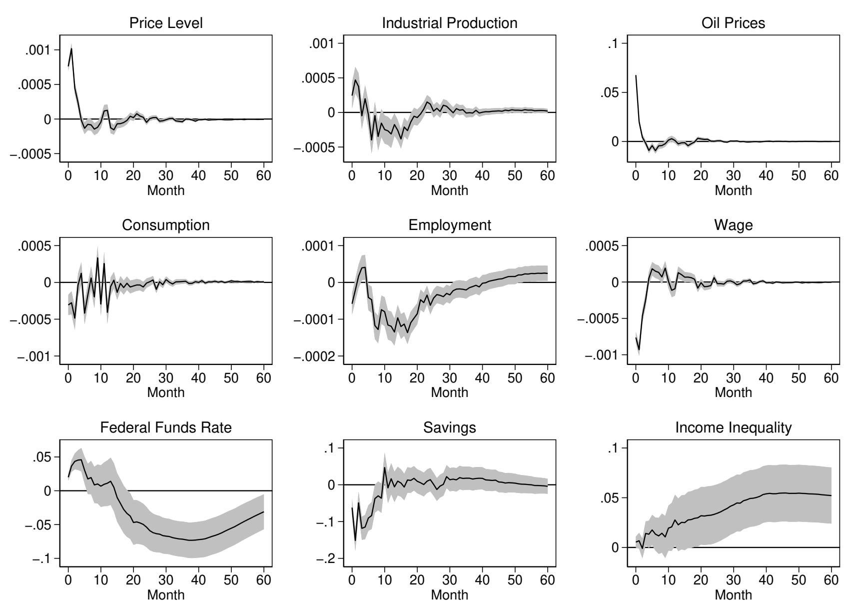


Figure 4: The Impact of Oil Price Changes on Income Inequality, from Local Projection on Monthly Data. (The gray area shows 68% confidence interval.)

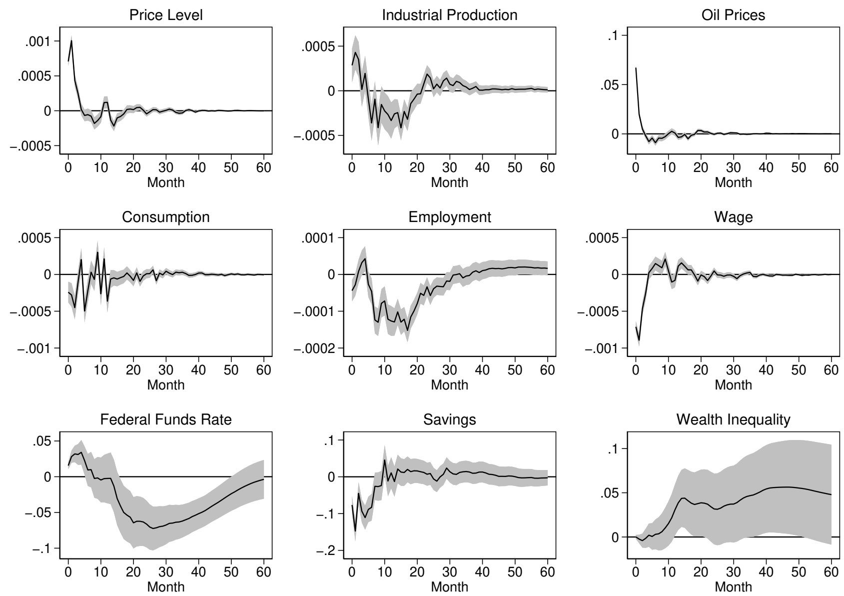


Figure 5: The Impact of Oil Price Changes on Wealth Inequality, from Local Projection on Monthly Data. (The gray area shows 68% confidence interval.)

# 4 Model

The model integrates two existing strands of literature. The first strand incorporates oil price shocks in the economy, *a la* Blanchard and Riggi (2013). Given that the United States was an energy net importer until 2019, we treat oil as imported goods and abstract away from the supply side of the oil market. Changes in world oil prices thus change the demand for oil in the US. [5] Instead, changes in world oil prices result in changes in oil demand. The second strand adopts an incomplete market model featuring idiosyncratic labor income risks as in Aiyagari (1994).

## 4.1 Households

Time is continuous. The economy consists of a unit mass of infinitely lived households (i.e.: $\bar{N} = 1$). Each household $i$ starts with zero financial wealth. They then work, accumulate capital, and rent their capital out to the firms. They receive labor income and capital income in the form of rental payments. Idiosyncratic labor income shocks contribute to heterogeneity in household income and wealth. Given prices $(p_{E,t}, p_t, w_t, r_t)$, households make consumption and savings decisions

[5] According to Bureau of Economic Analysis, the share of oil and gas extraction as a fraction of real GDP in the United States is merely 1.06% in 2019. Therefore, we do not explicitly model the production of oil.

continuously to solve the following optimization problem:

$$\max_{c_{i,t}} \mathbb{E} \int_0^\infty e^{-\rho t} \frac{c_{i,t}^{1-\phi}}{1-\phi} dt \tag{1}$$

where

$$c_{i,t} \equiv \left( (1-\xi)^{1-\sigma} c_{Y,i,,t}^{\sigma} + \xi^{1-\sigma} (c_{E,i,t} - \underline{c})^{\sigma} \right)^{\frac{1}{\sigma}} \tag{2}$$

Here, $\rho$ denotes the time discount rate. Agents have CRRA preferences over consumption. $\phi$ is the risk aversion coefficient. $c_{i,t}$ is a consumption bundle that consists of both final goods consumption $c_{Y,i,t}$ and oil-related goods $c_{E,i,t}$. $\xi$ adjusts the weight of oil-related goods in total consumption and $\sigma$ captures the elasticity of substitution between oil and final goods. agents have non-homothetic preferences in the sense that there exists a minimum level of oil goods consumption $\underline{c}$ for everyone.

Households maximize the consumption bundle by choosing $c_{E,i,t}$ and $c_{Y,i,t}$, given the prices of oil goods $p_{E,t}$ and final goods $p_{Y,t}$, and a certain level of income. The usage of oil-related goods are subject to a linear carbon tax rate $\tau_t$. Solving this maximization problem yields

$$c_{E,i,t} = \underline{c} + \xi \left( (1+\tau_t) \frac{p_{E,t}}{p_t} \right)^{\frac{1}{\sigma-1}} c_{i,t} \qquad \text{and} \qquad c_{Y,i,t} = (1-\xi) \left( \frac{p_{Y,t}}{p_t} \right)^{\frac{1}{\sigma-1}} c_{i,t} \tag{3}$$

where $p_t$ denotes the aggregate price, which features a combination of $p_{E,t}$ and $p_{Y,t}$ as

$$p_t \equiv \left( (1-\xi) p_{Y,t}^{\frac{\sigma}{\sigma-1}} + \xi (1+\tau_t)^{\frac{\sigma}{\sigma-1}} p_{E,t}^{\frac{\sigma}{\sigma-1}} \right)^{\frac{\sigma-1}{\sigma}} \tag{4}$$

To focus on the relative price between oil goods and final goods, we normalize $p_{Y,t} = p_Y = 1$ so that the aggregate price level is simplified to

$$p_t \equiv \left( 1 - \xi + \xi (1+\tau_t)^{\theta} p_{E,t}^{\theta} \right)^{\frac{1}{\theta}} \tag{5}$$

where $\theta = \frac{\sigma}{\sigma-1}$. Let the agent's (real) labor income follow a two-state Poisson process $z_t = [z_1, z_2]$ where $z_1$ denotes a low-income state and $z_2$ a high income state. The labor income jumps from the low state to the high state with a jump intensity $\lambda_1$, and from the high state to the low state with jump intensity $\lambda_2$. Therfore, the average labor income amounts to $\bar{z} = \frac{\lambda_1 z_2 + \lambda_2 z_1}{\lambda_1 + \lambda_2}$. Households' budget constraints read

$$da_{i,t} = (r_t a_{i,t} - c_{i,t} + w_t z_{i,t} + T_t) dt \tag{6}$$

where $a_{i,t}$ denotes real asset value, $r_t$ and $w_t$ are real rental rate and real wage, and that $T_t$ denotes the real lump sum transfer from the government, and is common across agents at time $t$.

In addition, a borrowing constraint states that

$$a_{i,t} \geq a_{min} \tag{7}$$

where $a_{min} \geq -\bar{z}/r^*$, and that $r^*$ denotes the equilibrium interest rate.

Let $V^1_{i,t}$, and $V^2_{i,t}$ denote the value function of the households currently in low and high-income state at time $t$ respectively, the individual Hamilton-Jacobian-Bellman (HJB) equations become

$$\rho V^1_{i,t} = \max_{c_{i,t}} \left[ \frac{c_{i,t}^{1-\phi}}{1-\phi} + \frac{\partial V^1_{i,t}}{\partial a_{i,t}}(r_t a_{i,t} - c_{i,t} + z_1 w_{i,t} + T_t) + \lambda_1 (V^2_{i,t} - V^1_{i,t}) \right] \tag{8}$$

$$\rho V^2_{i,t} = \max_{c_{i,t}} \left[ \frac{c_{i,t}^{1-\phi}}{1-\phi} + \frac{\partial V^2_{i,t}}{\partial a_{i,t}}(r_t a_{i,t} - c_{i,t} + z_2 w_{i,t} + T_t) + \lambda_2 (V^1_{i,t} - V^2_{i,t}) \right] \tag{9}$$

Away from the borrowing constraint, agents are able to smooth out consumption through the Euler equation, which reads

$$c^*_{1,i,t} = \left( \frac{\partial V^1_{i,t}}{\partial a_{i,t}} \right)^{-1/\phi} ; \qquad c^*_{2,i,t} = \left( \frac{\partial V^2_{i,t}}{\partial a_{i,t}} \right)^{-1/\phi} \tag{10}$$

However, at the borrowing constraint $a_{i,t} = a_{min}$, agents become hand-to-mouth, and can only consume their current income, i.e.:

$$c^*_{1,i,t}(a_{min}) = r_t a_{min} + w_t z_1; \qquad c^*_{2,i,t}(a_{min}) = r_t a_{min} + w_t z_2 \tag{11}$$

### 4.2 Final goods firm

The final goods market is competitive. The final goods firm produces final goods $Y_t$ by combining oil, capital, and labor with a Cobb-Douglas production function, i.e.:

$$Y_t = Z_t E_t^{\alpha} K_t^{\beta} N_t^{\gamma} \tag{12}$$

where $\alpha$, $\beta$ and $\gamma$ represent oil, capital and labor input share respectively, and that $\alpha + \beta + \gamma = 1$. This ensures zero profit. Firms take input cost $(p_{E,t}, p_t, w_t, r_t)$ as given, and optimize over real input demand $(E_t, K_t, N_t)$ to maximize profit. The usage of oil input is also taxed at a rate $\tau_t$. The firm's problem can thus be stated as

$$\max_{E_t, K_t, N_t} p_{Y,t} Y_t - (1+\tau_t) p_{E,t} E_t - r_t p_t K_t - w_t p_t N_t \tag{13}$$

Optimal input decisions then require the firm to equalize the marginal cost for each input. By normalizing the final goods price $p_{Y,t}$ to 1, the solutions to the above problem read

$$E_t^D = \left( (1+\tau_t) \frac{p_{E,t}}{\alpha Z_t K_t^{\beta} N_t^{\gamma}} \right)^{\frac{1}{\alpha - 1}} \tag{14}$$

$$K_t^D = \left(\frac{r_t p_t}{\beta Z_t E_t^\alpha N_t^\gamma}\right)^{\frac{1}{\beta-1}} \tag{15}$$

$$N_t^D = \left(\frac{w_t p_t}{\gamma Z_t E_t^\alpha K_t^\beta}\right)^{\frac{1}{\gamma-1}} \tag{16}$$

where the superscript $D$ denotes the optimal demand. Intuitively, the economy tends to enter a recession following an increase in oil prices for two primary reasons. Firstly, when holding the general price level $p_t$ constant, a rise in oil prices directly diminishes the demand for energy inputs, thus decreasing the productivity of both capital and labor. Thus, firms reduce the demand for capital and labor inputs. Secondly, an increase in oil prices also raises the general price level, leading to increased costs for capital and labor. This effect amplifies the reduction in demand for capital and labor inputs, further dampening overall output demand.

## 4.3 Aggregation

To close the model, we impose market-clearing conditions for oil goods, labor as well as capital. First, given that oil price is assumed to be imported, changes in oil prices determine the oil demand, which consists of demand for oil consumption and demand for oil input in production, i.e.:

$$E_t^* = E_t^D + \int_0^1 c_{E,i,t} di \tag{17}$$

Next, labor market clearing requires that labor demand equals the inelastic labor supply $\bar{N}$, i.e.:

$$N_t^* = N_t^D = \frac{\lambda_1}{\lambda_1 + \lambda_2}\bar{N} = \frac{\lambda_1}{\lambda_1 + \lambda_2} \tag{18}$$

Next, the capital market clearing condition states that total households' savings are equal to total productive capital.

$$K_t^* = K_t^D = \int_0^1 a_{i,t} di \tag{19}$$

Equations (17), (18) and (19), along with equations (14), (15), (16) jointly determine the wage rate, rental rate and equilibrium oil, capital and labor input.

Next, the government budget constraint states that

$$0 = \tau \frac{p_{E,t}}{p_t} E_t^D + \tau \frac{p_{E,t}}{p_t} \int_0^1 c_{E,i,t} di - T_t \tag{20}$$

That is, the total carbon tax revenue from households' and firms' oil usage equals to the total transfer. Finally, the goods market clearing condition states that

$$p_Y Y_t = p_Y \int_i c_{Y,i,t} di + p_E \int_i c_{E,i,t} di + p_E E_t^D \tag{21}$$

# 5 Equilibrium

In this section, we start by characterizing the equilibrium of this economy. The system of equations that characterizes the equilibrium requires the coupled Hamilton-Jacobian-Bellman equations and the Kolmogorov-Fokker-Plank equations (HJB-KFP), along with the aggregation conditions. Let $f_t(a, z)$ indicate the joint distribution of income and wealth at time $t$, we have

$$\rho V_{i,t}^1 = \max_{c_{i,t}} \left[ \frac{c_{i,t}^{1-\phi}}{1-\phi} + \frac{\partial V_{i,t}^1}{\partial a_{i,t}} (r_t a_{i,t} - c_{i,t} + z_1 w_{i,t} + T_t) + \lambda_1 (V_{i,t}^2 - V_{i,t}^1) \right] \quad \forall i \tag{22}$$

$$\rho V_{i,t}^2 = \max_{c_{i,t}} \left[ \frac{c_{i,t}^{1-\phi}}{1-\phi} + \frac{\partial V_{i,t}^2}{\partial a_{i,t}} (r_t a_{i,t} - c_{i,t} + z_2 w_{i,t} + T_t) + \lambda_2 (V_{i,t}^1 - V_{i,t}^2) \right] \quad \forall i \tag{23}$$

$$\frac{\partial f_t^1}{\partial t} = -\frac{\partial}{\partial a_t} (f_t^1 (r_t a_t - c_t + z_1 w_t + T_t)) - \lambda_1 f_t^1 + \lambda_2 f_t^2 \tag{24}$$

$$\frac{\partial f_t^2}{\partial t} = -\frac{\partial}{\partial a_t} (f_2^2 (r_t a_t - c_t + z_2 w_t + T_t)) - \lambda_2 f_t^2 + \lambda_1 f_t^1 \tag{25}$$

$$K_t^* = \int_0^1 a_{i,t} di = \int_{a_{min}}^{\infty} a_t f_t^1 da_t + \int_{a_{min}}^{\infty} a_t f_t^2 da_t \tag{26}$$

$$E_t^* = E_t^D + \int_0^1 c_{i,t}^E di \tag{27}$$

$$N_t^* = \frac{\lambda_1}{\lambda_1 + \lambda_2} \bar{N} = \frac{\lambda_1}{\lambda_1 + \lambda_2} \tag{28}$$

$$0 = \tau \frac{p_{E,t}}{p_t} E_t^D + \tau \frac{p_{E,t}}{p_t} \int_0^1 c_{E,i,t} di - T_t \tag{29}$$

$$p_Y Y_t = p_Y \int_i c_{Y,i,t} d\dot{i} + p_E \int_i c_{E,i,t} di + p_E E_t^D \tag{30}$$

$$a_{i,t} \geq a_{min} \quad \forall i \tag{31}$$

That is, the equilibrium in this model is given by household decisions $(c_{E,i,t}^*, c_{Y,i,t}^*)$, a set of aggregate variables $(K_t^*, E_t^*, N_t^*, C_t^*)$, and prices $(p_{E,t}, p_t, r_t, w_t)$ such that the HJB, the KFP, and the government budget constraint holds, and that the energy market, labor market, goods market and capital market clear. The above system of equations holds both in the steady state (when $f_t^1 = f_t^2 = 0$) as well as in the transition dynamics. In the following section, we will resort to numerical methods to compute the solution of the model. Detailed numerical methods are provided in the appendix.

# 6 Numerical Results

## 6.1 Energy price shocks

In this section, we begin by presenting the numerical results using calibrated parameters. To do this, we discretize the continuous time model above into annual frequency. We then present the steady state results, and the impulse response functions of the economy in response to a one-time positive and temporary oil price shock, which we assume follows an AR(1) process, that is,

$$p_{E,t+\delta} = p_{E,t}\rho_E^{\delta} dt \tag{32}$$

The persistence parameter of oil price shock $\rho_E$ equals 0.81, which is estimated using annual data on real crude oil prices spanning from 1985 to 2019, sourced from the U.S. Energy Information Administration (EIA). This then implies that the half-life of oil price shocks is determined to be 3.3 years.

## 6.2 Benchmark parameters

Table 1: Benchmark Parameter Values

| Parameters | Value | Data Source |
|---|---|---|
| $\phi$ | 2 | Standard value in the literature |
| $\rho$ | 0.05 | Standard value in the literature |
| $\gamma$ | 0.67 | Standard value in the literature |
| $z_1$ | 1 | Normalized to 1 |
| $z_2$ | 50 | Match income Gini coefficient |
| $\lambda_1$ | 0.0747 | Match average duration of unemployment |
| $\lambda_2$ | 2.84 | Match the average unemployment rate |
| $\underline{c}$ | 0.0013 | Match bottom group energy expenditure share |
| $\xi$ | 0.023 | Match the oil share out of total consumption |
| $\theta$ | 0.8 | Match the elasticity of substitution |
| $a_{min}$ | -1/3 | Match the maximum debt-to-income ratio |
| $\alpha$ | 0.017 | Oil share out of output |
| $\rho_E$ | 0.81 | Estimate using real annual crude oil price |

Table 1 presents the benchmark parameters used for the calibration exercise. We consider the standard value of $\phi = 2$, $\rho = 0.05$ and $\gamma = 0.67$ to be the level of risk aversion, time discount and labor share. For the labor income process, we first normalize the low-income state $z_1$ to one and then calibrate $z_2$ such that the steady state level income Gini coefficient matches the average income Gini between 1985-2019 using world income database information, which amounts to 0.55. Next, the average duration of unemployment is 20.3 week using the BLS data from 1985 to 2019. This gives an annualized job-finding rate of 0.928, which then implies a continuous time job-finding rate of $\lambda_1 = -log(0.928) = 0.0747$. We then use this value to calibrate the average annualized unemployment rate of $\frac{e^{-\lambda_2}}{e^{-\lambda_1}+e^{-\lambda_2}}$ [6] to match the average unemployment rate from 1985 to 2019 from BLS data of 5.9%. The implied value of $\lambda_2$ equals 2.84. Next, since the minimum level of oil goods consumption is mostly relevant to the bottom-income households, we calibrate $\underline{c}$ to match the total energy expenditure (including residential energy and commuting energy) share of the bottom 20% income group, which amounts to 11.1% as in Oni (2024). Following Bodenstein, Erceg, and Guerrieri (2011), the share of oil consumption out of total consumption composite $\xi$ is set to 2.3%. In contrast to other parameters within the model, the elasticity of energy substitution exhibits a broader spectrum of estimates, ranging from 0.1 to 0.4 across various studies. Here, the parameter $\theta$ is chosen so that the elasticity of substitution between oil goods and final goods equals 0.2, which matches the short-run average elasticity for households found in a meta-analysis in Labandeira, Labeaga, and López-Otero (2017). This then implies that $\sigma = \frac{\theta}{\theta-1} = -4$.[7] The parameter $a_{min}$ governing borrowing constraints is calibrated to match the maximum debt-to-income ratio of 2.06 across various U.S. states, leveraging data from the New York Fed and the BLS from 1999 to 2019. Following the methodology of Blanchard and Riggi (2013), the income share of oil in total output, denoted by $\alpha$, is set at 1.7%, which consequently determines the income share of capital, $\beta$, at 31.3% through the constant return to scale of production. Lastly, the steady state of real oil prices in the model is calibrated to match the average household energy consumption expenditure share, standing at 7.2% based on the NIPA and EIA data, assuming that carbon tax rate $\tau = 0$.

Using the calibrated parameters outlined above, the model yields an average marginal propensity to consume (MPC) of 0.22, aligning well within the broader spectrum of MPC estimates as observed in a recent meta-analysis conducted by Carroll, Slacalek, Tokuoka, and White (2017). Furthermore, the model generates a steady-state real interest rate of 3.2%, approximately corresponding to the annual real rate derived from the 1-year treasury bill discount basis, adjusted by the annual inflation rate in our sample period.

### 6.3 Simulation

Based on the calibrated model, we proceed to simulate the economy under a 50% increase in oil price. Figures 6 and 7 illustrate the impulse response functions of this shock on both aggregate and distributional variables over a span of up to 100 years. The vertical axis denotes the percentage deviation of the variables of interest from their respective steady-state values.

On impact, the increase in oil price increases the general price level and dampens aggregate output. The reduction in aggregate demand prompts firms to scale back production, leading to a decrease in demand for labor and capital, consistent with the effects of negative aggregate supply shocks. Both consumption (including consumption on final goods and oil goods) and investment decline.

To understand the short-run and medium-run effects on the income inequality responses, notice

[6] Here, $e^{-\lambda_1}$ is the annualized job finding rate, and $e^{-\lambda_2}$ is the annualized job separation rate.

[7] In the following section, we will conduct a counterfactual analysis with alternative values of this elasticity parameter.

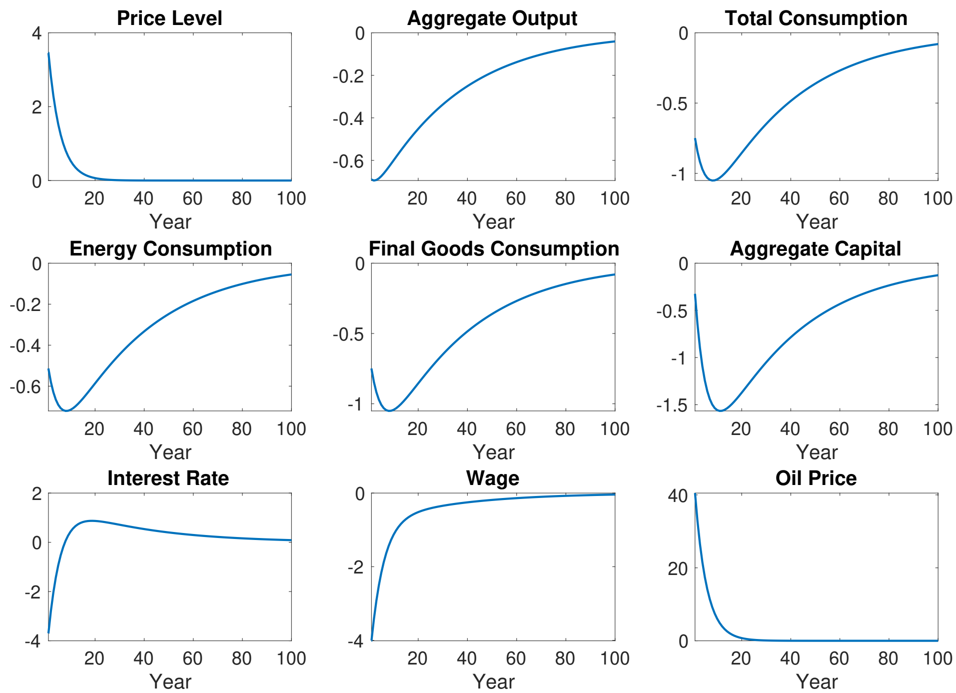


Figure 6: Impulse response functions (Unit: $\Delta\%$ from steady state)

that in the short run, a positive oil price shock results in an immediate reduction in wages as well as interest rate. It is worth noting that interest rate reduces slightly less than wages upon the shock due to a decrease in capital supply. While the initial difference is relatively small, with the gradual decline of aggregate capital stock, the marginal product of capital rises over time, subsequently elevating the interest rate immediately post-shock. Given that income inequality hinges on the horse race between labor and capital income, our findings indicate that, in the short term, declines in labor income outweigh those in capital income, leading to a peak of income Gini at 0.13% above the steady-state level. [8] Transitioning to the medium term, the persistence of inequality responses becomes apparent. Capital stock gradually rebounds while the interest rate surpasses its steady-state level, persisting at a high level even after reaching its peak. This persistence stems from the fast recovery in capital demand post-shock, while capital supply requires time to accumulate. In the medium term, the elevated levels of interest rates overshadow the regained wage levels, leading to sustained increases in income inequality.

[8] Even though we assume that labor supply is inelasitc here, the gap between capital income and labor income would widen further with endogenous labor supply. Empirical evidence suggests that the substitution effect outweighs the income effect in labor supply response to wage changes. Therefore, a decrease in wages would result in a decrease in labor supply. With sticky wages, this could potentially escalate unemployment rates, exacerbating income inequality even more.

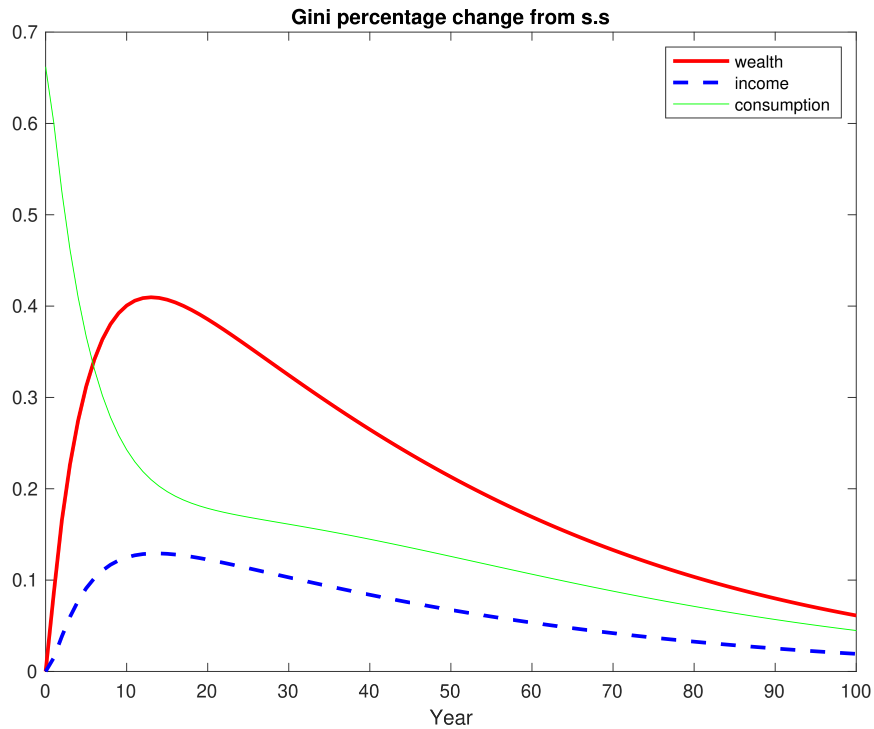


Figure 7: Impulse response functions (Unit: $\Delta\%$ from steady state)

Next, notice that the initial consumption inequality response is much larger than the increase in income and wealth inequality. Two opposite forces contribute to the changes in consumption inequality. On one hand, rising oil prices diminish real income, prompting individuals to shift towards regions with higher MPCs. This encourages poorer individuals to reduce consumption to a lesser extent relative to their wealth, potentially decreasing consumption inequality. On the other hand, many agents who were previously operating on the Euler equation now find themselves living hand-to-mouth, eroding their capacity to smooth consumption altogether, thus exacerbating consumption inequality. Quantitatively, the latter effect proves to be more significant, and the consumption Gini index rises more than the increase in income inequality, with its initial rise peaking at 0.66% relative to its steady state value. It also decreases rapidly as the economy rebounds, when the poor become less borrowing constrained.

Lastly, the evolution of wealth inequality results from a combination of changes in income and consumption inequality. To observe shifts in wealth inequality, variations in wealth growth rates among individuals are necessary. Recall that the flow budget constraint for an individual with wealth $a_{i,t}$ can be written as:

$$\frac{da_{i,t}}{a_{i,t}} = r_t + \frac{w_t z_{i,t}}{a_{i,t}} - \frac{c_{i,t}}{a_{i,t}} \tag{33}$$

Here, the uniform decrease in $r_t$ for all does not influence wealth growth rates for those on the Euler equation but can help to compress the wealth distribution if many agents are hand-to-mouth. However, since labor income constitutes a smaller fraction of wealthier individuals' income, the second term exacerbates inequality by reducing wealth growth more for the poor. The third term, linked to the consumption-to-wealth ratio, hinges on whether individuals live hand-to-mouth. After the oil price shock, everyone becomes poor. On one hand, poor households who are on the Euler equation experience less reduction in consumption relative to their wealth, since they have a higher MPC. On the other hand, those hand-to-mouth households must disproportionately scale back their consumption compared to those adhering to their Euler equation. The first effect becomes stronger as one travels further to the right tail of the wealth distribution. Therefore, the net effect of the last term on changes in wealth inequality is ambiguous in general, depending on which part of the wealth distribution we focus on. Quantitatively, we witness the net changes of the three components of wealth accumulation rises, peaking at 0.41% above the steady-state level, and it gradually declines only when the interest rate starts to decrease.

While examining the impulse response of Gini coefficients offers a broad understanding of inequality shifts, it is important to note that this is merely one metric. Studying the Gini coefficient does not specify whether inequality rises due to the poor getting poorer, the rich getting richer, or the middle class shifting towards the distribution extremes. To gain deeper insights into winners and losers, we next focus on the change of various quantiles of the distribution.

Figure 8 illustrates the impact of the oil price shock on each 20% percentile of the distribution, measured in percentage changes at their peaks. [9] The graph reveals that the bottom 60% experience losses, while the top 40% gains. However, the extent of change varies across income, consumption, and wealth. Firstly, changes in income share follow a monotonic trend, with the bottom 20% witnessing a 0.025% reduction in percentage share, while the top 20% observe a 0.039% increase. Secondly, changes in consumption share do not mirror those in income share, particularly evident at the bottom. Despite the bottom 20% losing 0.17% in consumption share, the $20-40\%$ group experiences an even greater loss of almost 0.2%. This disparity arises because many households in this group were previously operating on the Eurer equation before the shock, but now find themselves hand-to-mouth, leading to a sharper decline in consumption share compared to income share, unlike the bottom 20%, many of whom were already hand-to-mouth before the shock. Finally, wealth share changes are again monotonic, with the top 20% gaining almost 0.12% in response to the shock.

# 7 Counterfactual analysis

The baseline simulation results suggest that a temporary increase in oil prices can cause an increase in income, consumption, and wealth inequality. One may wonder how these effects on

[9] It is worth noting that these three inequality measures do not reach their peaks simultaneously, with the consumption Gini peaking first, followed by income and wealth Gini.

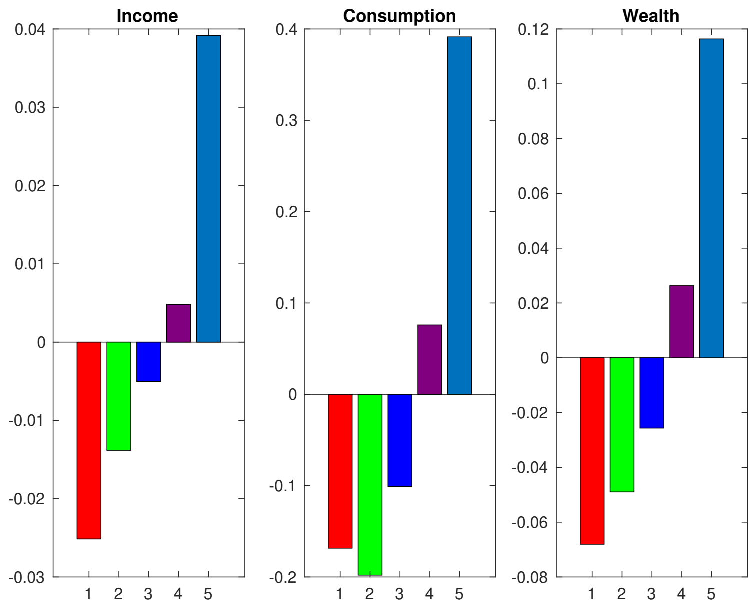


Figure 8: Changes in shares in response to one std.oil price increase ($\Delta\%$)
Group 1: bottom 20%, Group 2: bottom $20-40\%$, Group 3: middle $40-60\%$, Group 4: middle $60-80\%$, Group 5: Top 20%

inequality may depend on oil intensity in consumption and production, the elasticity of substitution between oil and final goods consumption, the direction of oil price shocks, the borrowing constraints of the households, and various taxation policies on oil usage. To provide insight into these questions, we conduct several counterfactual analyses based on the baseline model.

## 7.1 Varying oil share

We first explore a counterfactual scenario where energy input share out of production is reduced by 50%. This requires a change of $\alpha$ to 0.85% from its baseline of 1.7%, while holding all other parameters constant at their baseline levels. The results are shown in Figures 9 and 10. As displayed, the impact of oil price shocks on various aggregate variables, such as capital, output, and consumption, is mitigated in the scenario where energy input is halved. This is because firms experience lesser adverse effects from heightened oil prices when the intensity of oil usage in production is reduced. Notably, the relative reduction of wage to interest rate is less pronounced. Consequently, the effects on income, consumption, and wealth inequality are dampened.

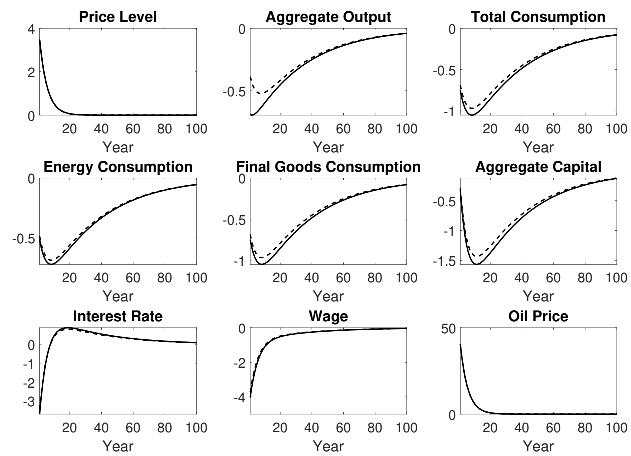


Figure 9: Impulse response functions when $\alpha = 0.85\%$. Solid (dashed) lines represent the impulse responses estimated from the baseline (counterfactual) scenario.(Unit: $\Delta\%$ from steady state)

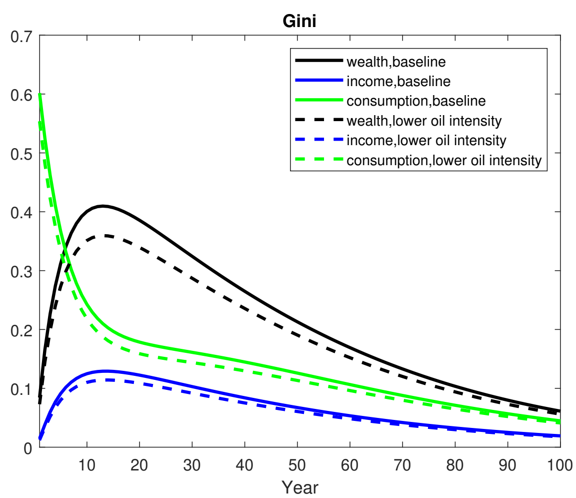


Figure 10: Impulse response functions when $\alpha = 0.85\%$ (Unit: $\Delta\%$ from steady state)

Secondly, we look into an alternative scenario where households' oil consumption share is reduced by 50%, i.e.: $\xi = 1.15\%$. The outcomes of this simulation are presented in Figures 11 and 12. As the share of oil consumption diminishes within the consumption bundle, the impact of oil prices on the overall price level, as well as aggregate demand are notably less noticeable. Consequently, the oil price shock effect on aggregate variables, as well as income, consumption, and wealth inequality are muted.

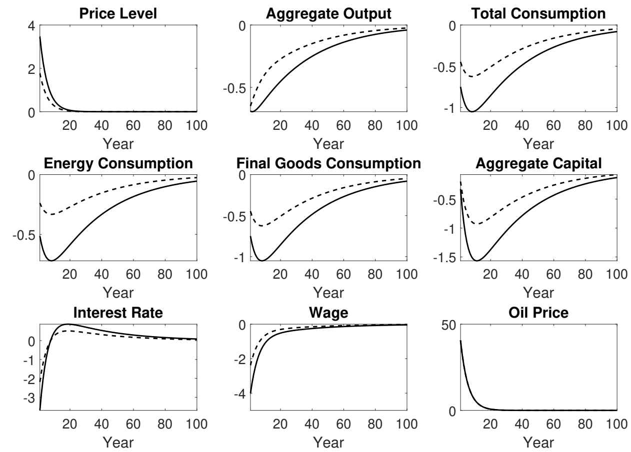


Figure 11: Impulse response functions when $\xi = 1.15\%$. Solid (dashed) lines represent the impulse responses estimated from the baseline (counterfactual) scenario.(Unit: $\Delta\%$ from steady state)

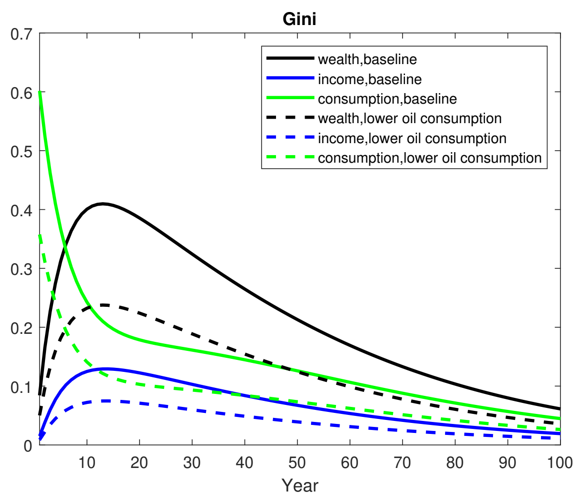


Figure 12: Impulse response functions when $\xi = 1.15\%$ (Unit: $\Delta\%$ from steady state)

## 7.2 Varying oil elasticity

In this section, we conduct a simulation experiment wherein we increase the elasticity of substitution between oil and final goods by 50%, denoted as a shift from $\sigma = -4$ to $\sigma = -2.33$. The comparison outcomes are depicted in Figures 13 and 14. When households can easily switch from using oil to using other goods when oil prices go up, they are less bothered by the oil price increases. This flexibility helps cushion the effects on things like overall economic activity and income and wealth inequality.

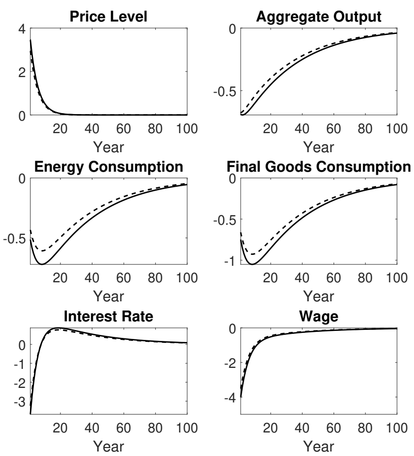


Figure 13: Impulse response functions when $\sigma = -2.33$. Solid (dashed) lines represent the impulse responses estimated from the baseline (counterfactual) scenario. (Unit: $\Delta\%$ from steady state)

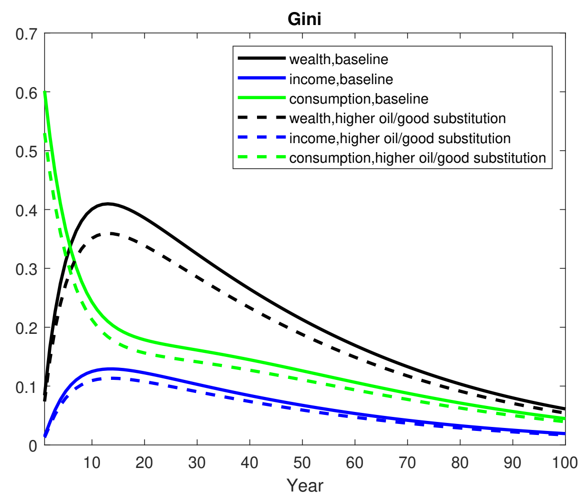


Figure 14: Impulse response functions when $\sigma = -2.33$. Solid (dashed) lines represent the impulse responses estimated from the baseline (counterfactual) scenario. (Unit: $\Delta\%$ from steady state)

## 7.3 Asymmetric responses to oil price shocks

In the following counterfactual analysis, we explore the asymmetric effects of oil price shocks. Specifically, we ask ourselves: does inequality decrease with the same magnitude and persistence in response to a negative vs. positive oil price shock? Figure 15 and Figure 16 show the responses of macro variables and Gini coefficients by comparing a 50% increase in oil prices vs a 50% decrease in oil prices under benchmark parameters.

Following a negative oil price shock, the economy experiences an expansion, marked by a decline in the price level and an expansion across various metrics including energy demand, capital stock, wages, interest rates, consumption, and output. This response of aggregate dynamics is more pronounced compared with the case of a positive shock. This is due to the concavity of the aggregate price function. As oil prices decline, households tend to shift their consumption from final goods to oil-related goods. This results in a more significant decrease in the overall price level compared to the increase that would occur if oil prices rose by the same amount. This has two effect. On the supply side, firms increase their demand for inputs more than proportionally due to the lower input costs, which boosts aggregate supply. On the demand side, the substantial drop in the price level stimulates overall consumption, leading to an increase in aggregate demand. Both effects contribute to a more expansionary economy compared to the contraction that would occur if oil prices increased by the same amount. Consequently, the reduction in income, consumption, and wealth inequality is also greater than the potential increase in inequality from a positive oil price shock.

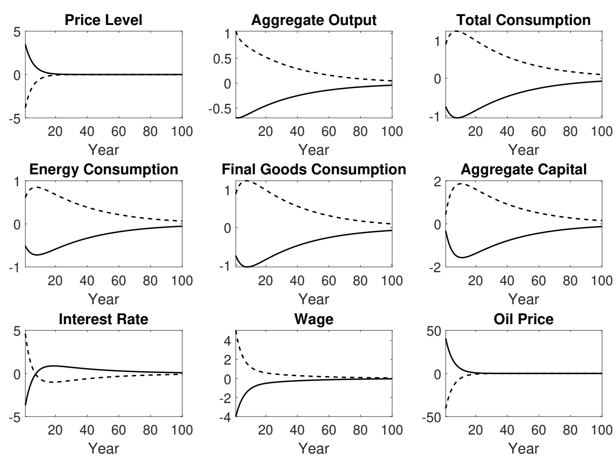


Figure 15: Impulse response functions to positive (solid lines) and negative (dashed lines) oil price shocks (Unit: $\Delta\%$ from steady state)

## 7.4 Borrowing constraints

In this section, we illustrate the influence of borrowing constraints on the correlation between oil prices and inequality. Figures 17 and 18 show responses of aggregate variables and inequality to an equally sized oil price shock in both the baseline economy and one with a no-borrowing constraint, i.e., $a_{min} = 0$. Our findings indicate that while borrowing constraints insignificantly impact aggregate variables, they do influence the response of inequality to a great extent. When borrowing is not allowed, an increase in oil prices exhibits weaker effects on both income and

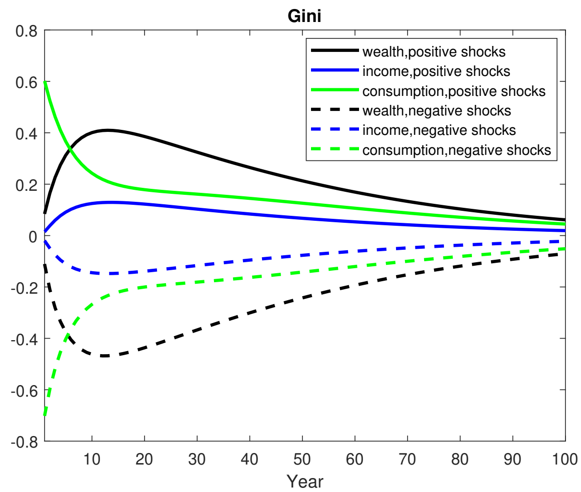


Figure 16: Impulse response functions to positive (solid lines) and negative (dashed lines) oil price shocks (Unit: $\Delta\%$ from steady state)

wealth inequality since the poor households are now forced to save rather than to borrow, which then compresses the income and wealth distribution. The increase of consumption inequality is amplified initially due to the fact that there are now more hand-to-mouth households. However, it quickly diminishes and follows the pattern of income and wealth inequality in subsequent periods, as the influence of income and wealth inequality starts to dominate the dynamics of consumption inequality.

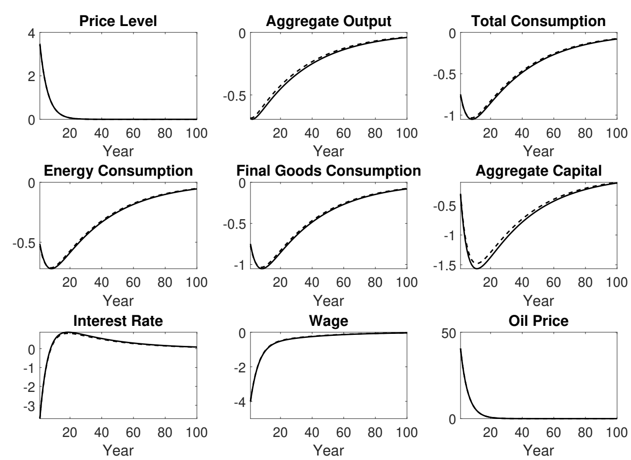


Figure 17: Impulse response functions when $a_{min} = -0.33$ (solid lines) and when $a_{min} = 0$ (dashed lines). (Unit: $\Delta\%$ from steady state)

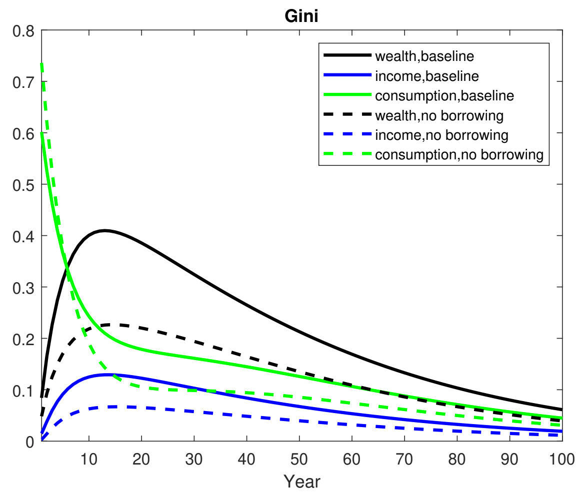


Figure 18: Impulse response functions when $a_{min} = -0.33$ (solid lines) and when $a_{min} = 0$ (dashed lines). (Unit: $\Delta\%$ from steady state)

### 7.5 A carbon tax experiment

In this section, we explore the effects of fiscal policy, specifically a carbon tax, on macro aggregates and distributional variables. The analysis in this section operates under the assumption that crude oil is the sole energy source in the economy, therefore we only focus on short to medium-run transition dynamics. In particular, we examine the transitional dynamics of inequality under a typical proposed carbon fee in Congress, which entails the sudden increase of a carbon tax followed by a gradual increase in the tax rate, aimed at reducing fossil fuel consumption over time.

To do this, we follow the approach suggested by the 10 carbon pricing proposal in the 116th Congress, in which a carbon tax ("carbon fee") would be first introduced, then gradually rise over time until certain fossil fuel emission goals are achieved. Each proposal differs in terms of the emissions covered. As a result, they differ in the starting level of the tax, and how quickly it increases over time. Here, we take a typical American Opportunity Carbon Fee Act (i.e.: Whitehouse-Schatz proposal), for example, which suggests setting a $52 fee per metric ton of Co2 emission from 2020 (which then translates into an equivalent initial carbon tax rate $\tau = 39\%$), [10] and then rises at 6 percent above inflation rate annually until emissions are 80 percent below the 2005 levels. Further, since changes in the aggregate price level is driven by changes in the oil prices, inflation then solely stems from increases in the carbon tax. We therefore conduct a policy experiment as such by

[10] According to the EPA, carbon dioxide emissions per barrel of crude oil are determined by a series of multiplications: the heat content is multiplied by the carbon coefficient, which is then multiplied by the fraction oxidized, and finally, this product is multiplied by the ratio of the molecular weight of carbon dioxide to carbon (44/12). With the average heat content of crude oil being 5.80mmbtu per barrel (EPA 2023), an average carbon coefficient of 20.31 kg carbon per mmbtu (EPA 2023), and assuming a 100 percent oxidation rate (IPCC 2006), the emissions from one barrel of crude oil are calculated to be 0.43 metric tons. Given a carbon fee of $52 per ton, this translates to $22.36 per barrel. Considering the 2019 average annual crude oil price (West Texas Intermediate) of $57 per barrel, the effective carbon tax rate is $22.36/$57, which equals 39%.

allowing a 30-year transition with an incremental 6% increase of carbon tax rate annually until 2050, where carbon tax is used as lump sum transfers.

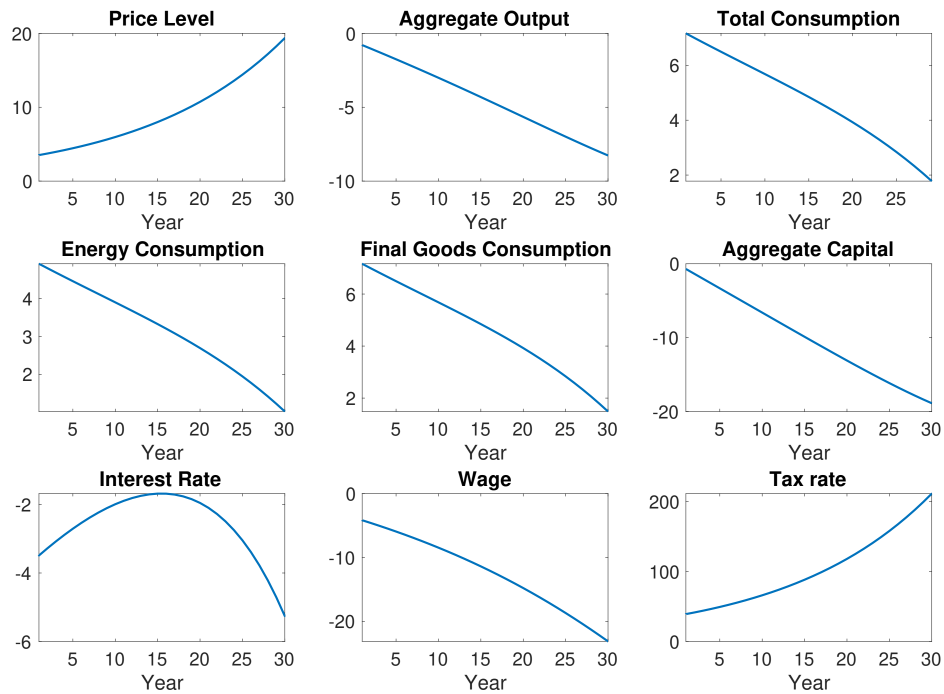


Figure 19: Transition dynamics of aggregate variables (Unit: $\Delta\%$ from steady state)

Figure 19 and Figure 20 show the transition dynamics of the macro aggregates and Gini coefficients from 2020 to 2050. The results show that the aggregate economy contracts in response to the introduction of the tax, featuring an immediate increase in price level and a reduction in aggregate output, wages and interest rate, followed by further gradual decline. The only exception is the consumption variable, which witnesses an increase above the steady state value for roughly 20 years before dipping down. Income and wealth Gini coefficients increase by 4.89% and 15.7% respectively at the end of the 2050. However, as the carbon tax hike progresses, so does the lump sum transfer, which has equalizing effect on the consumption distribution. Consumption inequality immediately decreases by 5.41% upon the initial introduction of the carbon tax due to the lump sum tax rebate, and continues to decline to 7.91% below the baseline level in 2050.

What is particularly interesting here is that the dynamic carbon tax policy triggers a short-run consumption boom, which can be attributed to two major channels. Firstly, the transfer channel: with a higher after-transfer income, the economy experiences a temporary consumption surge. This occurs because not only has after-transfer income risen, but also because the transfer acts as an insurance mechanism, allowing agents to afford to dissave and consume. Secondly, the inflation

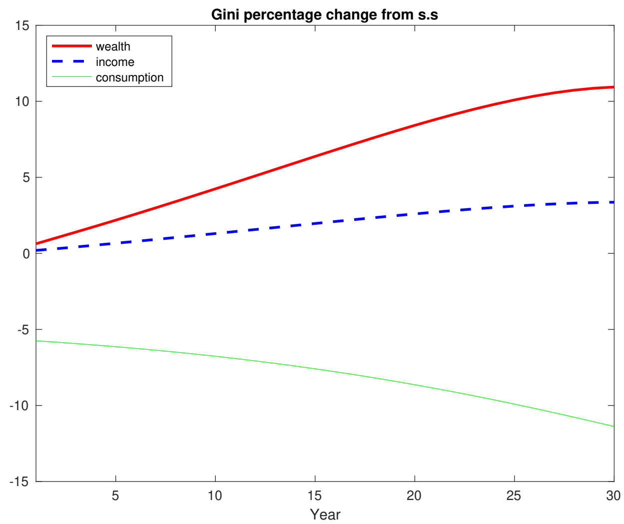


Figure 20: Gini change from 2019 level (Unit: $\Delta\%$ from steady state)

channel: as households anticipate future tax hikes that are embedded in an anticipated increase in future price levels, which boosts current consumption demand. In other words, the carbon tax policy here has the flavor of forward guidance by triggering higher inflation expectations. [11] However, this consumption surge is transient. After approximately 15 years, aggregate consumption must decline due to output reductions. It is important to note that this does not alter the fact that consumption inequality continues to decrease, while income and wealth inequality continue to rise. The former is predominantly driven by transfers, whereas the latter is primarily influenced by the relative price changes of capital and labor during economic contraction.

# 8 Conclusion

This is the first paper that systematically examines the impact of oil price fluctuations on the dynamics of consumption, income and wealth inequality in an oil-importing economy. By analyzing data of macroeconomic aggregates, oil prices, and inequality, our study shows that a rise in oil prices triggers a sustained surge in inequality. To decompose the channels at which oil price shocks affect distributional variables, we delve into a continuous-time heterogeneous agent model where oil serves as both a consumption good and a production input. We then calibrate the model to the U.S. data during the Great moderation period. Our findings reveal that a temporary positive oil price shocks yield substantial and lasting increases in consumption, income, and wealth inequality. The dynamics of the inequality response suggest that while the short-run increase in inequality

[11] Quantitatively, the first channel holds greater significance in explaining the short-term consumption boom, as evidenced by the counterfactual analysis without transfers (additional results available upon request).

stems from the rise in the relative price of capital and labor, the persistent elevation of inequality, in the medium run, is propelled by the sluggish recovery of capital supply.

The framework presented in our study lays the groundwork for several compelling extensions and future explorations. For instance, incorporating oil production and enabling endogenous fluctuations of oil prices could offer insights into how the distributional effects of oil price shocks hinge upon the market power of oil production. Additionally, it could shed light on the consequence of oil price shocks on oil-exporting economies, particularly as domestic oil production gains higher market share in the international oil market. Another intriguing avenue for investigation would involve introducing stochastic shocks in oil prices, which can potentially yield more nuanced implications for inequality as agents adapt their behavior in response to varying levels of uncertainty of future oil price shocks.

Lastly, the analysis in this paper operates under the assumption that crude oil is the sole energy source in the economy. However, the implementation of a carbon tax is likely to incentivize households and businesses to gradually transition towards cleaner alternative energy sources. After all, that is why the carbon tax is proposed at the first place. Therefore, it would be worthwhile to investigate how carbon fiscal policies impact inequality when alternative energy options are available during the transition dynamics. This might induce a milder recession but an amplification of inequality, since transitioning to clean energy typically involves substantial initial costs, which could again potentially disproportionally benefit the rich.

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# Appendices

## A Data Description

| Variable | Source | Definition |
|---|---|---|
| Real GDP | Bureau of Economic Analysis | The inflation adjusted value of the goods and services produced by labor and property located in the United States |
| CPI | Bureau of Labour Statistics | The price of a weighted average market basket of consumer goods and services purchased by households. |
| Hours Worked | Bureau of Labour Statistics | Hours worked for all workers in the Non-Farm Sector. |
| Federal Funds Rate | Federal Reserve Board | The nominal interest rate at which depository institutions lend reserve balances to other depository institutions overnight on an uncollateralized basis. |
| Crude Oil Prices | Energy Information Administration | Crude oil spot prices (dollars per barrel) deflated by CPI |
| T. Employment | Bureau of Labour Statistics | The number of U.S. workers in the economy that excludes proprietors, private household employees, unpaid volunteers, farm employees, and the unincorporated self-employed. |
| Real Pers. Expend. | Bureau of Economic Analysis | The nominal change in goods and services consumed by all households, and nonprofit institutions serving households, deflated by CPI |
| Investments | Bureau of Economic Analysis | Measure of the amount of money that domestic businesses invest within the U.S. |
| Wages | Bureau of Labour Statistics | Median usual weekly real earnings for full time workers 16 years and older. |
| Savings | Bureau of Economic Analysis | Calculated as the ratio of personal saving to disposable income. |
| Top 1% Wealth (Income) | Federal Reserve Board | Percentage of wealth (income) by the top 1% of U.S. households |
| Bottom 50% Wealth (Income) | Federal Reserve Board | Percentage of wealth (income) held by the bottom 50% of U.S. households |

Table 2: Data definition: all variables (1985 - 2019)

# B Numerical methods

Following Achdou, Han, Lasry, Lions, and Moll (2022), we employ a combination of the finite difference method and a linearization procedure to solve and simulate the model. To solve for the steady state, we begin by initializing the interest rate $r^0$ and the wage rate $w^0$. The iterative process for each step $k = 0, 1, 2, \ldots$ proceeds as follows:

1. Given $r^k$ and $w^k$, we solve for the energy demand $E^D$ using the firm's first-order conditions (FOCs) and the labor market clearing condition.

2. The capital demand $K^D$, the implied carbon tax revenue, and the subsequent wage rate $w^{k+1}$ are then computed.

3. We solve the Hamilton-Jacobi-Bellman (HJB) equation using the finite difference method (implicit method), supplemented with an upwind scheme.

4. The Kolmogorov Forward (KFP) equation is then solved, and aggregate savings are computed.

5. We check for the presence of excess savings. If aggregate savings are positive, we set $r_{\max}$ for the next iteration to $r^k$ and update the interest rate as the average of $r_{\min}$ and $r^k$. Conversely, if aggregate savings are negative, we set $r_{\min}$ to $r^k$ and update the interest rate as the average of $r_{\max}$ and $r^k$.

6. Steps 1-5 are repeated until convergence is achieved.

To solve the transition dynamics, we adopt a similar iterative approach. First, we assume a path for aggregate savings $K^k(t)$, which is presumed to be equal to the steady-state value for all $t$. The following steps are then iterated:

1. Given the assumed path $K^k(t)$, we compute the implied interest rate $r^k(t)$ and solve the savings decision path in the HJB equation backward, utilizing the fact that the value function at the terminal point corresponds to its steady-state value.

2. Using the optimal savings path, we solve the KFP equation forward, with the initial condition that the joint distribution of income and wealth at the initial time is also equal to its steady-state value.

3. The solutions from steps 1 and 2 are combined to compute the path of aggregate savings.

4. If the resulting path of aggregate savings is not sufficiently close to that obtained in the previous iteration, we update $K^k(t)$ to $K^{k+1}(t)$ using a relaxation method.

5. Steps 1-4 are repeated until convergence is achieved.