Dynamic Stochastic General Equilibrium - Heterogenous Agent New Keynesian (DSGE-HANK) models for monetary and fiscal policy analysis

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Student's Declaration

I hereby declare that the work presented in the report entitled **"Dynamic Stochastic General Equilibrium - Heterogenous Agent New Keynesian (DSGE-HANK) models for monetary and fiscal policy analysis"** submitted by me for the partial fulfillment of the requirements for the degree of *Bachelor of Technology* in *Computer Science & Engineering* at Indraprastha Institute of Information Technology, Delhi, is an authentic record of my work carried out under guidance of **Kiriti Kanjilal**. Due acknowledgements have been given in the report to all material used. This work has not been submitted anywhere else for the reward of any other degree.

Deepam Sarmah **Place & Date: IIIT-D, November 29, 2023**

Certificate

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Kiriti Kanjilal **Place & Date: IIIT-D, November 29, 2023**

Abstract

Dynamic Stochastic General Equilibrium (DSGE) models are the workhorse of modern macroeconomics. They are used to study the effects of monetary and fiscal policy, and to understand the sources of business cycle fluctuations. However, the standard DSGE models are not able to explain the observed heterogeneity in the data. The Heterogenous Agent New Keynesian (HANK) models are an extension of the standard DSGE models that incorporate heterogeneity in the data. The HANK models are able to explain the observed heterogeneity in the data, but they are computationally expensive. In this thesis, we develop a HANK model for monetary and fiscal policy analysis. We use the model to study the effects of monetary and fiscal policy shocks on the economy. We also perform a sensitivity analysis of the model to understand the effects of changes in the parameters of the model on the results.

Keywords: DSGE Models, Steady State Equilibrium, HANK Models, Business Cycle Fluctuations, Monetary Policy, Fiscal Policy, Sensitivity Analysis

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Contents

Chapter 1

Introduction

1.1 General Equilibrium

In macroeconomics, general equilibrium refers to a state in which all markets in an economy reach a state of balance, where the quantity demanded for every good or service equals the quantity supplied, and all agents (consumers, producers, and firms) maximize their utility or profits given the prevailing prices and constraints. In a general equilibrium setting, prices adjust to ensure that the quantity demanded equals the quantity supplied in each market. This equilibrium takes into account not only the supply and demand for goods but also factors of production like labor and capital. It encompasses the idea that the economy operates efficiently when all markets are in equilibrium, leading to an optimal allocation of resources. The study of general equilibrium helps economists understand how various policies or external shocks affect the overall economy, as changes in one sector can have widespread implications throughout the interconnected network of markets and economic agents.

1.2 Dynamic Stochastic General Equilibrium (DSGE) Models

In accordance to [4] Dynamic stochastic general equilibrium (DSGE) models are a type of macroeconomic framework rooted in microeconomic fundamentals. They're widely used by central banks and international organizations to analyze policies and make forecasts. What sets them apart is their multi-period structure compared to the single-period focus of most macroeconomic models. The "dynamic" aspect means they consider multiple time periods, while "stochastic" implies they factor in various shocks or disturbances that impact business cycle fluctuations. These shocks are pivotal in understanding how changes in one variable affect others and for what duration. The stochastic nature forms the foundation for policy analysis, recommendations, and forecasting.

These models operate within a general equilibrium framework, examining all sectors of the economy simultaneously to achieve aggregate-level equilibrium. Understanding the economy as a whole is crucial for policymakers to gauge the effects of policy changes comprehensively.

Partial equilibrium analysis falls short in providing this holistic view, hence its unsuitability for policymaking. Over time, DSGE models have undergone extensive research and witnessed substantial growth in literature. Initially, they were categorized as Real Business Cycle models, assuming a simplistic economic structure with perfect price flexibility. However, challenges emerged from New Keynesians who emphasized the role of monetary authority, leading to a shift in focus. Presently, a new breed of DSGE models has surfaced, incorporating behavioral elements to explain macroeconomic phenomena, gaining significant attention and traction in recent times.

1.3 Real Business Cycle (RBC) Models

According to [5], RBC theory firmly established the use of dynamic stochastic general equilibrium (DSGE) models as a central tool formacroeconomic analysis. Behavioral equations describing aggregate variables were thus replaced by first-order conditions of intertemporal problems facing consumers and firms. Ad hoc assumptions on the formation of expectations gave way to rational expectations. In addition, RBC economists stressed the importance of the quantitative aspects of modelling, as reflected in the central role given to the calibration, simulation, and evaluation of their models. The most striking dimension of the RBC revolution was, however, conceptual. It rested on three basic claims:

- *The efficiency of business cycles*: The bulk of economic fluctuations observed in industrialized countries could be interpreted as an equilibrium outcome resulting from the economy's response to exogenous variations in real forces (most importantly, technology), in an environment characterized by per- fect competition and frictionless markets. According to that view, cyclical fluctuations did not necessarily signal an inefficient allocation of resources (in fact, the fluctuations generated by the standard RBC model were fully optimal). That view had an important corollary: Stabilization policies may not be necessary or desirable, and they could even be counterproductive. This was in contrast with the conventional interpretation, tracing back to Keynes (1936), of recessions as periods with an inefficiently low utilization of resources that could be brought to an end by means of economic policies aimed at expanding aggregate demand.
- *The importance of technology shocks as a source of economic fluctuations*: That claim derived from the ability of the basic RBC model to generate "realistic" fluctuations in output and other macroeconomic variables, even when variations in total factor productivity—calibrated to match the properties of the Solow residual are assumed to be the only exogenous driving force. Such an interpretation of economic fluctuations was in stark contrast with the traditional view of technological change as a source of long term growth, unrelated to business cycles.
- *The limited role of monetary factors*: Most important, given the subject of the present

monograph, RBC theory sought to explain economic fluctuations with no reference to monetary factors, even abstracting from the existence of a monetary sector.

1.4 Representative Agent New Keynesian (RANK) Models

The Representative Agent New Keynesian Model (RANK) is a theoretical framework used in macroeconomics to study how various factors influence economic outcomes, particularly in the context of short-run fluctuations and the role of monetary policy. In this model, the economy is simplified by representing all individuals or households as a single "representative agent" that makes decisions on behalf of the entire population. This simplification allows economists to analyze the overall behavior of the economy without considering individual differences among households or firms.

Key features of the Representative Agent New Keynesian Model include:

- *New Keynesian Principles*: It builds upon Keynesian economics, emphasizing nominal rigidities, such as sticky prices or wages, that can lead to short-term fluctuations in output and employment even in response to monetary policy changes.
- *Dynamic Optimization*: The representative agent maximizes utility over time, taking into account intertemporal trade-offs between consumption and saving. This dynamic optimization helps to understand how households allocate resources over time.
- *Nominal Rigidities*: Prices and wages are assumed to be sticky or rigid in the short run, meaning they do not adjust immediately to changes in economic conditions. This rigidity can lead to market inefficiencies and contribute to economic fluctuations.
- *Monetary Policy*: Central to this model is the role of monetary policy in influencing economic activity. By adjusting interest rates or money supply, policymakers can impact inflation, output, and employment levels.
- *Business Cycles*: The RANK model aims to explain fluctuations in output and employment over the business cycle, highlighting the importance of monetary policy in stabilizing the economy.

This model is often used for policy analysis and forecasting by central banks and policymakers due to its ability to simulate the effects of different policy interventions, especially those related to monetary policy, on the overall economy. However, it's important to note that the simplification of representing the entire economy through a single "representative agent" has its limitations, as it overlooks heterogeneity and distributional effects among individuals and firms in the real world.

1.5 Heterogenous Agent New Keynesian (HANK) Models

In accordance to the paper [6] The HANK model stands for "Heterogeneous Agent New Keynesian" model, representing a more sophisticated approach in macroeconomic analysis compared to the Representative Agent New Keynesian (RANK) model. The HANK model acknowledges and incorporates individual heterogeneity among agents in the economy, unlike the assumption of a representative agent in the RANK model. This heterogeneity is important to consider because it can have significant implications for the overall economy, especially in the context of monetary policy.

Key features include:

- *Heterogeneous Agents*: Instead of assuming a single representative agent, the HANK model incorporates diverse individuals or households with varying characteristics, preferences, income levels, and access to credit or financial markets. This heterogeneity allows for a more realistic representation of the economy.
- *Income and Wealth Inequality*: The model accounts for differences in income and wealth distribution among households, recognizing that not all agents face the same economic conditions or constraints.
- *Labor Market Frictions*: It considers frictions in the labor market, such as wage rigidities and variations in labor market participation across different groups of individuals.
- *Monetary Policy Effects*: Similar to the RANK model, the HANK model focuses on the influence of monetary policy on economic outcomes. However, it takes into account the heterogeneous responses of different agents to changes in interest rates or other policy measures.
- *Financial Constraints*: Recognizing differences in access to credit and financial markets among households, the HANK model studies how these constraints affect consumption, investment, and overall economic dynamics.
- *Aggregate Demand and Fluctuations*: By incorporating the interactions between heterogeneous agents and their consumption, saving, and labor choices, the HANK model aims to explain how these factors collectively contribute to aggregate demand fluctuations and business cycle dynamics.

The HANK model and its inclusion of heterogeneity allows for a more comprehensive analysis of policy implications compared to models that assume a homogeneous representative agent.

1.6 Econpizza

Econpizza is a Python package for solving and estimating HANK models. It is developed by [1]. The package heavily relies on the JAX package [3], which is a Python library for fast numerical computation through automatic differentiation. The package is available at `https://pypi.org/project/econpizza/`

1.6.1 Automatic Differentiation

Automatic Differentiation is a set of techniques to numerically evaluate the derivative of a function specified by a computer program. It is also known as algorithmic differentiation, or simply, autodiff. Automatic differentiation is neither symbolic differentiation nor numerical differentiation, but a third way of computing derivatives of functions. It exploits the fact that every computer program, no matter how complicated, executes a sequence of elementary arithmetic operations (addition, subtraction, multiplication, division, etc.) and elementary functions (exp, log, sin, cos, etc.). By applying the chain rule repeatedly to these operations, derivatives of arbitrary order can be computed automatically, accurately to working precision, and using at most a small constant factor more arithmetic operations than the original program.

Chapter 2

Literature Review

As part of this thesis, we went over the following papers:

- HANK on Speed: Robust Nonlinear Solutions using Automatic Differentiation [2]
- A behavioral New Keynesian model [4]
- Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework and its applications [5]
- Monetary policy according to HANK [6]

Chapter 3

Problem statement

In this thesis, we take a HANK model developed by [2] and use it to study the effects of monetary and fiscal policy shocks on the economy. We also perform a sensitivity analysis of the model to understand the effects of changes in the parameters of the model on the results.

Chapter 4

Model

The following model revolves around the 2 asset HANK model. The model is developed by [2]. In the disaggregated part of the model, households can hold liquid bonds b_{it} and illiquid assets a_{it}, the latter pay higher returns but are subject to convex portfolio adjustment costs. Households face idiosyncratic labor income risk e_{it} and a borrowing constraint on both assets. They wish to accumulate net worth for the purpose of consumption smoothing and to insure against associated idiosyncratic income risk. Their Bellman equation is given by:

$$V_t(e_{it}, b_{i,t-1}, a_{i,t-1}) = \max_{c_{it}, a_{it}, b_{it}} \{ \frac{c_{it}^{1-\sigma_c}}{1-\sigma_c} - \chi \frac{n_t^{1+\sigma_t}}{1+\sigma_t} + \beta \mathbb{E}_t V_{t+1}(e_{i,t+1}, b_{i,t+1}, e_{it}) \} \tag{4.1}$$

such that

$$c_{it} + a_{it} + b_{it} = \frac{(1-\tau_t) w_t n_t}{\int P(e_{jt}) e_{jt}^{1-\xi} dj} e_{it}^{1-\xi} + (1+r_t) a_{i,t-1} + (1+r_t^b) b_{i,t-1} - \Phi_t(a_{it}, a_{i,t-1}) + T_t \tag{4.2}$$

$$a_{it} \geq 0$$

$$b_{it} \geq 0$$

where n_t denotes labour supply, c_{it} the consumption of household i, and e_{it} is their household specific labour productivity which follows an AR(1) process in logs,

$$\log e_{it} = \rho \log e_{it-1} + \epsilon_{it}^e \tag{4.3}$$

$\Phi(\cdot)$ is the function specifying portfolio adjustment costs for the illiquid asset.

$$\Phi_t(a_{it}, a_{i,t-1}) = \frac{\chi_1}{\chi_2} \left| \frac{a_{it} - (1+r_t^a) a_{i,t-1}}{(1+r_t^a) a_{i,t-1} + \chi_0} \right|^{\chi_2} [(1+r_t^a) a_{i,t-1} + \chi_0] \tag{4.4}$$

with $\chi_0, \chi_1 > 0$ and $\chi_2 > 1$. T_t is a government lump-sum transfer.

Chapter 5

Sensitivity Analysis

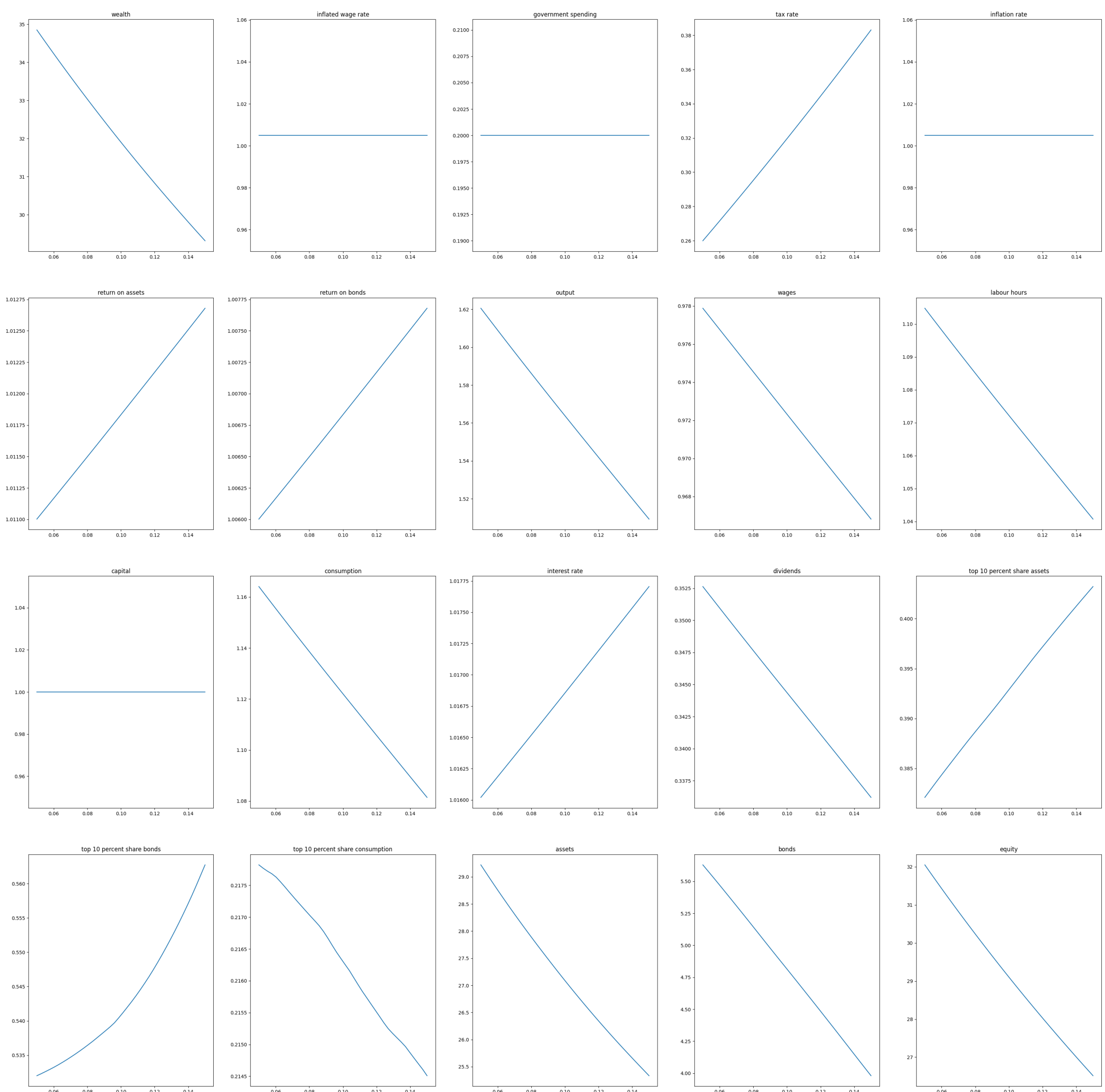
We analyze the impact of changing the government transfers rate, T_t, inflation rate π and also analyze the impact of changing the portfolio adjustment cost parameters, χ_0, χ_1, χ_2, on the steady state values of the economy.

5.1 Government Transfers Rate

We vary the government transfer rate T by considering 40 data points between 5% and 15% and look at how it impacts the following steady state values of the economy: (the variables mentioned are with respect to the YAML file [1])

- Output: Y
- Wages: w
- Labour Hours: n
- Capital: q
- Consumption: C
- Interest Rate: $Rstar$
- Dividends: div
- Top 10% share assets: $Top10A$
- Top 10% share bonds: $Top10B$
- Top 10% share consumption: $Top10C$
- Assets: A
- Bonds: B

- Inflation: *pi*
- Equity: *equity*
- Tax Rate: *tax*
- Wealth: *wealth*
- Inflated wage rate: *piwn*
- Government Spending: *g*
- Return on Assets: *Ra*
- Return on Bonds: *Rb*

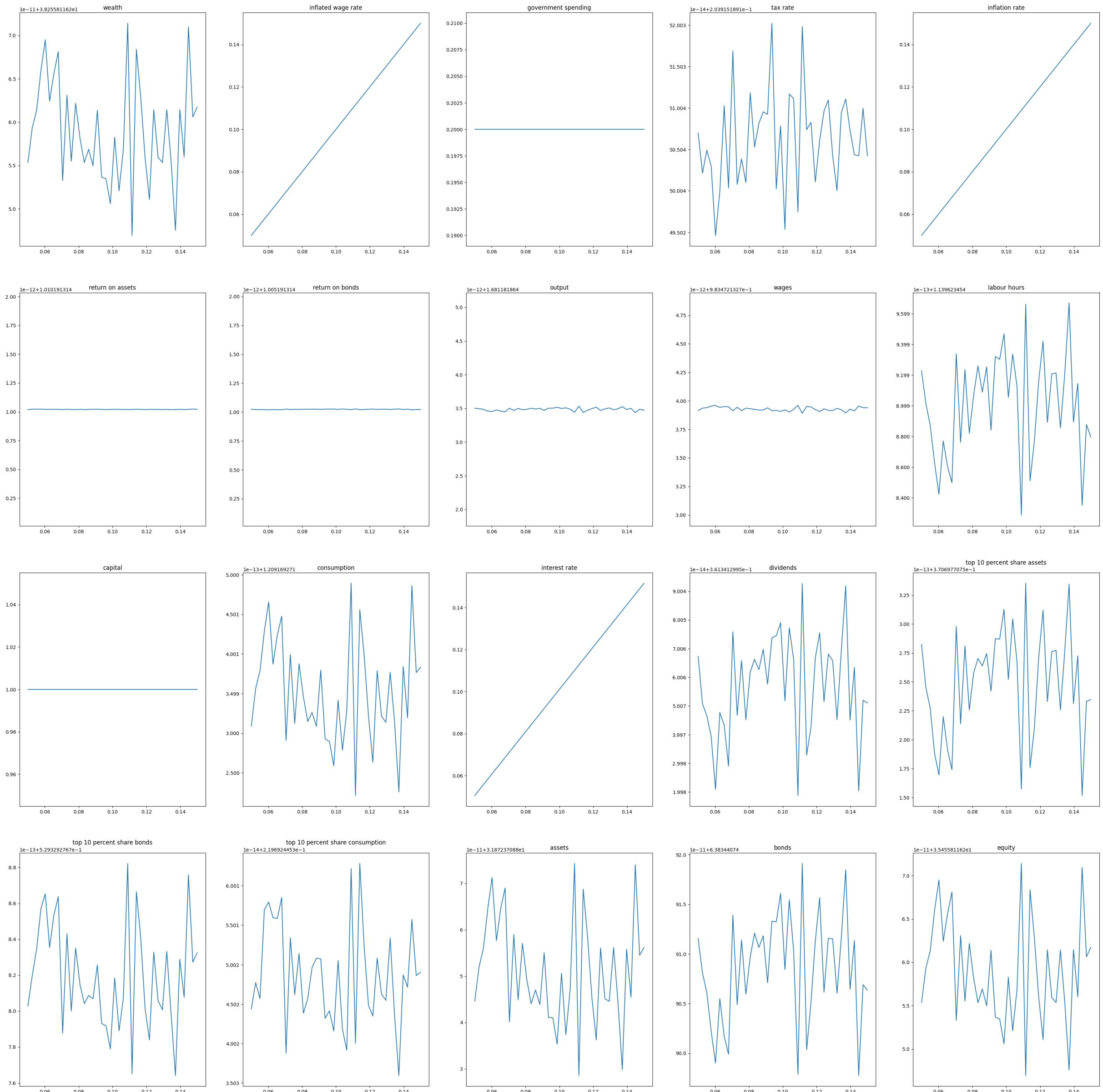


We observe that as the government transfers rate increases, the output, wages, labour hours, consumption, interest rate, dividends, top 10% share assets, top 10% share bonds, top 10% share consumption, assets, bonds, equity, wealth, inflated wage rate, government spending, return on assets and return on bonds increase. The capital decreases as the government transfers rate increases. The inflation rate and tax rate remain constant.

5.2 Inflation Rate

We vary the inflation target rate π by considering 40 data points between 5% and 15% and look at how it impacts the following steady state values of the economy: (the variables mentioned are with respect to the YAML file [1])

- Output: Y
- Wages: w
- Labour Hours: n
- Capital: q
- Consumption: C
- Interest Rate: $Rstar$
- Dividends: div
- Top 10% share assets: $Top10A$
- Top 10% share bonds: $Top10B$
- Top 10% share consumption: $Top10C$
- Assets: A
- Bonds: B
- Inflation: pi
- Equity: $equity$
- Tax Rate: tax
- Wealth: $wealth$
- Inflated wage rate: $piwn$
- Government Spending: g
- Return on Assets: Ra
- Return on Bonds: Rb



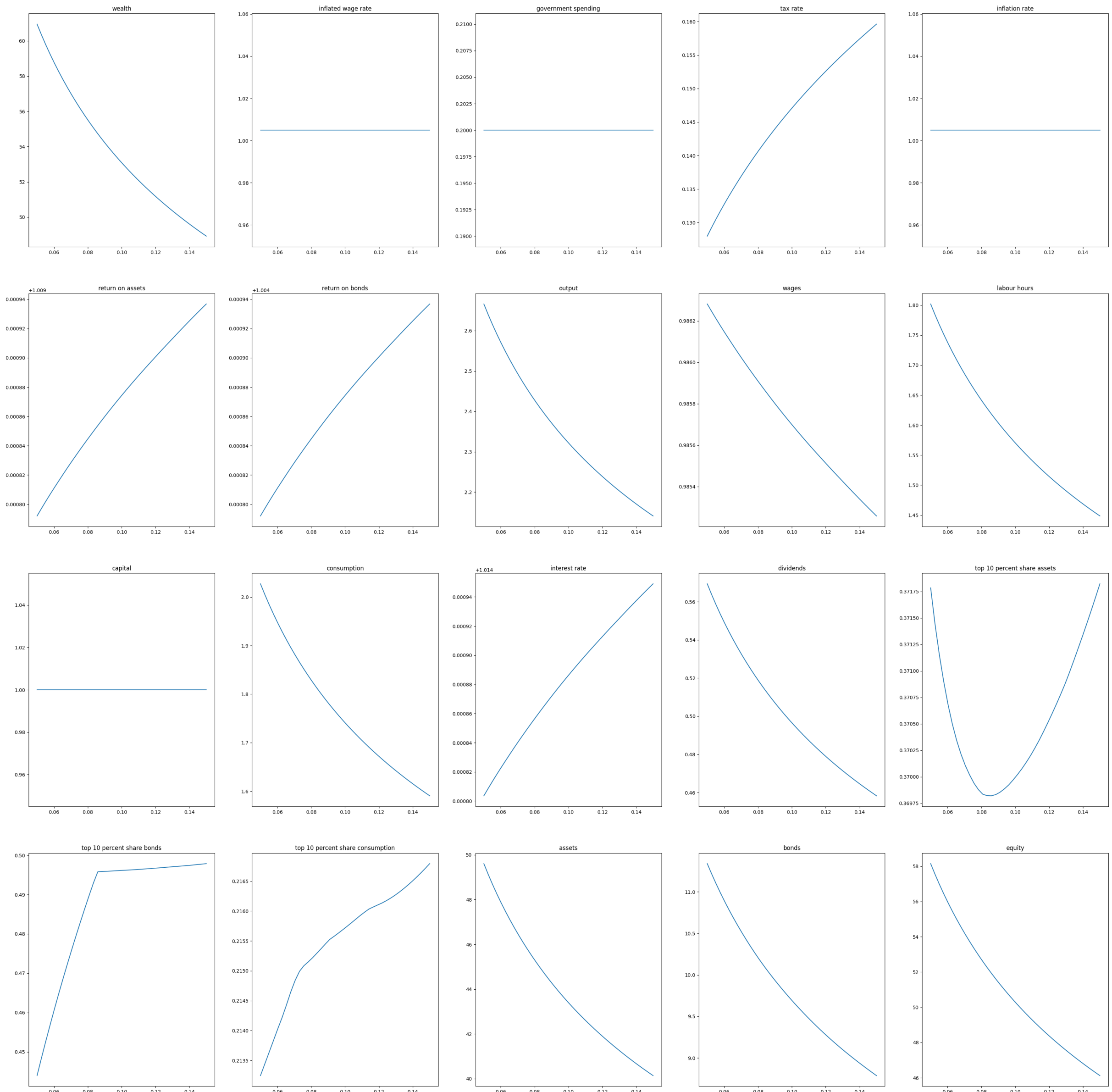
We observe that as the inflation target rate increases, the output, wages, labour hours, consumption, interest rate, dividends, top 10% share assets, top 10% share bonds, top 10% share consumption, assets, bonds, equity, wealth, inflated wage rate, government spending, return on assets and return on bonds increase. The capital decreases as the inflation target rate increases. The tax rate remains constant.

Due to downward wage rigidity, as inflation increases the wages cannot decrease beyond a certain limit. Due to this labour hours increase as the inflation increases. As labour hours increase, the output increases. As the output increases, the consumption increases. As the consumption increases, the interest rate increases. As the interest rate increases, the dividends increase. As the dividends increase, the top 10% share assets, top 10% share bonds, top 10% share consumption, assets, bonds, equity, wealth, inflated wage rate, government spending, return on assets and return on bonds increase.

5.3 Portfolio Adjustment Cost Parameters

We vary the utility weight of labor disutility χ and look at how it impacts the following steady state values of the economy: (the variables mentioned are with respect to the YAML file [1])

- Output: Y
- Wages: w
- Labour Hours: n
- Capital: q
- Consumption: C
- Interest Rate: $Rstar$
- Dividends: div
- Top 10% share assets: $Top10A$
- Top 10% share bonds: $Top10B$
- Top 10% share consumption: $Top10C$
- Assets: A
- Bonds: B
- Inflation: pi
- Equity: $equity$
- Tax Rate: tax
- Wealth: $wealth$
- Inflated wage rate: $piwn$
- Government Spending: g
- Return on Assets: Ra
- Return on Bonds: Rb



We observe that as the utility weight of labor disutility χ increases, the output, wages, labour hours, consumption, interest rate, dividends, top 10% share assets, top 10% share bonds, top 10% share consumption, assets, bonds, equity, wealth, inflated wage rate, government spending, return on assets and return on bonds increase. The capital decreases as the utility weight of labor disutility χ increases. The tax rate remains constant.

Chapter 6

Technology Readiness Level (TRL)

The technology readiness level of my thesis is level 1 as the basic principles have been observed and fundamental research has been conducted.

Chapter 7

Conclusion

In this thesis, we developed a HANK model for monetary and fiscal policy analysis. We used the model to study the effects of monetary and fiscal policy shocks on the economy. We also performed a sensitivity analysis of the model to understand the effects of changes in the parameters of the model on the results.

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