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Bachelor thesis International Economics

Monetary Policy and Income Inequality: a comparison between HANK model predictions and empirical shocks

Name student: Florian Peter-Tijs Martend van Genderen

Student ID number: 512715

Supervisor: R. Silvestrini

Second assessor: A.P. Markiewicz

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Abstract

This paper studies the relationship between monetary policy shocks, income inequality in the United States and HANK model predictions given a certain level of income inequality, represented by the gini coefficient. To estimate the effects of monetary policy shocks, I employ a VAR methodology similar to Christiano et al. (2005) on quarterly data from 1967-2019. I compare the effects of monetary policy shocks during different periods of income inequality and look at the qualitative predictive capabilities of a simple HANK model. Next, I identify a structural break in income inequality and split the sample accordingly. I find different response functions regarding consumption, GDP, inflation and the gini coefficient for both income inequality periods. Moreover, the HANK model predictions during high income inequality more closely resemble the effects present in the data.

1. Introduction

Monetary policy has a long history and continues to be a topic of lively debate. A new topic to this discussion is the possibility of heterogeneous policy effects and the relation to inequality. This paper further studies both topics by investigating the differences in the effects of monetary policy shocks under different periods of income inequality. Moreover, I qualitatively compare predictions of heterogeneous agent New Keynesian models between high and low-income inequality.

Multiple studies since the famous paper of Piketty and Saez (2003) show that inequality is rising. A few examples are Feenstra and Hanson (2008) regarding trade and wage inequality and Heathcote, Storesletten and Violante (2010), who show that United States (US) earnings inequality has been rising during the last five decades. Moreover, Heathcote, Violante and Perri (2020) established that recession might have persistent detrimental effects on low wage groups, thus, further stimulating inequality. In addition, on the theoretical side, Bayer, Born and Luetticke (2020) argue that a strong driver of income inequality consists of income risk. Moreover, Auclert and Rognlie (2020) find that rising income inequality can have lasting large adverse effects if it is due to increasing income risk.

Oppositely to these findings on the rise of inequality, no consensus amongst scholars was present on the effects of monetary policy on inequality. Namely, Galbraith (1998) found that strict inflation targeting policies induced multiple busts and thus caused higher unemployment and rising inequality. Contrary, Doepke and Schneider (2006) argued that low-interest rates induced by expansionary policy primarily hurt savers and benefits borrowers. However, more recent empirical works show more consistent findings focusing on the effects of monetary policy on inequality. For instance, both Mumtaz and Theophilopoulou (2017) and Coibion, Gorodnichenko, Kueng and Silvia (2017) find that contractionary policy increases labour earnings, income and consumption inequality. And Auclert (2019) found that expansionary policy tends to benefit those households whose maturing liabilities are greater than their assets. Furthermore, Coibion et al. identify multiple channels through which monetary policy affects households. The primary focus lies on the composition, portfolio, savings redistributional and heterogeneous earnings channel. Mumtaz et al. also mention differences in propagation due to the durability of goods. It must be stressed that these effects are both direct and indirect of nature.

Also, recent additions to the theoretical field show that monetary policy affects inequality both via direct and indirect effects (Gornemann, Kuester & Nakajima (2016). Kaplan, Moll and Violante (2018) established that indirect effects dominate the transmission channels of monetary policy, fundamentally caused by uninsurable risk combined with both liquid and illiquid asset portfolios. It is paramount, because according to Bilbiie (2020), uninsurable risk warrants a HANK model. Otherwise, a two agent new Keynesian (TANK) might have been sufficient. Another vital factor is the effect of marginal propensity to consume (MPC). Especially differences in it. For instance, O'Farrell, Rawdanowicz and Inaba (2016) show that the existence of distinct MPCs for different deciles plays a major role in induced changes due to monetary policy. Related is the paper of Luetticke (2021), who uses different marginal propensities to invest in a heterogeneous agent new Keynesian (HANK) model. Although this is beyond the scope of this paper, it shows that studying such heterogeneous effects requires models which can handle them.

Yet, with a vast and growing literature on both HANK models, inequality and monetary policy, there exists no cross-period comparison between the empirical effects of monetary policy and HANK model predictions. As I will show, a structural break in income inequality exists, which I utilize to compare pre and post model predictions and empirical observations. Moreover, inequality is becoming a topic of capital importance, and HANK models are the main theoretical tool of macroeconomists at the moment. Thus, tracking both the effect of monetary policy given differences in inequality and comparing it to model predictions focuses on two very relevant aspects of macroeconomics. Therefore, the two primary research questions of this paper are (1) *what are the differences in the effects of US monetary policy on consumption, gross domestic product, inflation and income inequality between periods of high and low income inequality. And (2) are HANK* *models able to qualitatively predict the effects of US monetary policy on consumption, gross domestic product and inflation, given heterogeneous household portfolios and income present in the data.*

The primary reason to look at the US is the vast amount of data and existing literature on income inequality and HANK models that focus on the US. Moreover, I focus solely on income inequality. The reason is rather practical of nature since income inequality is well documented by the gini coefficient. Also, model calibration focusing on income inequality alone proved more straightforward. The model I use is a simplified version of the incomplete-markets HANK model with nominal rigidities and business cycles of McKay and Reis (2016). The most important aspect is that it uses business cycles. Namely, Bayer, Born and Luetticke (2020) argue that models focusing on income inequality should take business cycles into account.

The remainder of this paper is structured as follows. First section 2 provides an overview of related HANK literature. Next, section 3 describes the empirical part of the paper. It consists of the data, looking at US income inequality specifically and the methodology to identify monetary policy shocks. Consequently, section 4 describes both the model and the model calibration. Afterwards, section 5 discusses both empirical and simulation results and compares them. Lastly, section 6 concludes, discusses some caveats and provides future research suggestions.

2. Related literature

The origins of HANK models

As stated, the literature on heterogeneous agent new Keynesian models is vast and growing. A few examples are HANK models focusing on transfer payments (Oh & Reis, 2012), Heterogeneous portfolios (Luetticke, 2021), forward guidance (McKay, Nakamura & Steinsson, 2016) and, of course, monetary policy transmission (Auclert 2019, Kaplan et al. 2018). However, HANK models find their origin in Mankiw's (1989) introduction of two agent new Keynesian (TANK) models. In this paper, they tried to improve on the representative agent new Keynesian (RANK) models of their time by distinguishing between two different types of agents present in the data. Usually, such models distinguish between hand-to-mouth consumers (Schmitt-Grohe & Uribe, 2003) and unconstrained agents. Hand-to-mouth consumers are those who consume their income each period, whilst unconstrained agents can fully operate in the asset market and thus save or insure themselves. An example of a TANK model is that of Galí et al. (2007) where the authors try to account for empirical evidence regarding fiscal policy. Another famous example that uses two different types of agents is the HANK model of Ravn and Sterk (2020).

A comparison between HANK and TANK models

Although this was a big step forward in understanding heterogeneity among agents, it still only utilized two distinct agents. Therefore, TANK models can only capture a limited type of variability, as Debortoli and Galí (2018) and Bilbiie (2020) show. Debortoli and Galí built a framework that encompasses a general Euler equation and identifies three types of variance between unconstrained and constrained households. TANK models can only capture changes in the consumption gap between agent types. However, HANK models can also capture changes in the share of constrained households and variations in consumptions dispersity within the unconstrained households. Accordingly, TANK models seem to be able to capture some variation but are not able to fully grasp complicated problems such as the effect of monetary policy on income distributions. Furthermore, Bilbiie shows that TANK and HANK models are different regarding persistent shocks and news shocks that address the future. It needs to be said that he also showed that TANK models are a big improvement regarding RANK models. They can either amplify or dampen policy effects, thus, putting back the Keynesian cross in new Keynesian models. However, in TANK models agents are not able to self-insure against idiosyncratic shock. It can be especially problematic when studying income inequality since idiosyncratic shocks can matter a lot. Namely, Bayer, Born and Luetticke (2020) concluded that income risk is a major driver of income inequality. Kaplan, Moll and Violante (2018) add even more to this case. They exhibit that contrary to TANK models, high liquid wealth holders, do not increase their consumption much after expansionary monetary policy. The risk of negative income shocks and future binding borrowing constraints captured by HANK models diminish it. Bayer, Born and Luetticke also compare RANK and HANK models and find that latter puts more emphasis on household savings. It is again in line with Bilbiie's (2020) view since saving can be seen as a form of insurance.

Transmission of monetary policy in HANK models

Now it is clear that HANK models can capture more complex forms of heterogeneity, it is also important to take a closer look at the existing transmission channels. Benjamin Moll (2010) identifies several channels. First, direct effects can consist of intertemporal substitution or income effects. However, Kaplan, Moll and Violante (2018) show that indirect effects dominate. Therefore, the remainder of the literature focuses on those effects. The indirect transmission channels, in turn, consists of three main categories: fiscal policy, asset prices and labor income. An important paper that focuses primarily on labor income is Auclert's (2019). Auclert focuses on the effects of monetary policy and the redistributional channel. He identifies three distinct channels that amplify the effects of monetary policy. The first channel is earnings heterogeneity due to unequal increases in income. Secondly, a Fischer (1933) channel from unexpected inflation, as also explored by Doepke and Schneider (2006). And thirdly the interest rate exposure channel via real interest rates. However, these channels only amplify the effects of monetary policy if the MPCs of the winners are higher than those of the losers. Said winners or losers depends on the changes in either interest rate or inflation. For instance, if the interest rate increases, holders of short term-assets gain. Contrary, adjustable-rate mortgage owners lose.

Furthermore, Kaplan Moll and Violante (2018) built a framework that encompasses all categories. As stated, they show that indirect effects dominate in HANK models. It is fundamentally caused by uninsurable risk combined with both liquid and illiquid asset portfolios. Therefore, the consumption between hand-to-mouth and unconstrained agents differs significantly. It counteracts the substitution effect and decreases direct effects. They also show that monetary and fiscal policy are largely intertwined due to the failure of Ricardian equivalence. The government is a large issuer of liquid debt and, thus, monetary policy shocks affect the budget constraint of a government profoundly.

Consequently, the model I use must focus on indirect effects, as the model McKay and Reis (2016) does. It primarily utilizes the indirect effects of fiscal policy. Also, uninsurable income risk is present in their model. It applies to the impatient households of the model. Therefore, consumption patterns are expected to differ between the two inequality periods due to differences in the MPCs of both agents. However, the model I use is far more simplified than Auclert's (2019) and does, for instance, not contain adjustable-rate mortgages as assets. Since Auclert further primarily focused on the indirect effects of labor income, his transmission channels are beyond the scope of this paper.

3. Data and empirical methodology

This section is organized into three parts. First, I describe the data and provides summary statistics. Next, I further investigate US income inequality and identify a structural break. Thirdly, I discuss the empirical methodology I use to determine the effects of monetary policy shocks.

Data description and summary statistics

To identify monetary policy shocks I use data on real gross domestic product (GDP), real consumption, real investment, the GDP deflator, real wage, real labor productivity, the growth rate of M2 and the federal funds rate. All series, except real wage and real labor productivity, are from the FRED (2021) database. Both series on the real wage and real labor productivity are from the US bureau of labor statistics (2021). Moreover, to include income inequality in the analysis I use the gini coefficient as reported by the US census (2021). Summary statistics are reported in Table 1 below.

Variable	*Observations*	*Mean*	*St. Dev.*	*Min*	*Max*
Consumption	209	7084.673	3113.32	2710.014	13093.15
GDP	209	10706.82	4360.084	4535.591	18950.35
Investment	209	1648.402	858.5628	530.378	3481.311
Inflation	209	0.0085284	0.0058249	-0.0014551	0.0285795
Interest rate	209	0.0526957	0.0389228	0.0007	0.1908
Productivity	209	37.55463	39.28798	2.833705	133.6297
Wage	209	58.82397	34.89289	14.73889	141.8584
M2 growth	209	0.0161616	0.008655	-0.0022865	0.0457793
Gini	209	0.4390395	0.0318999	0.386	0.486

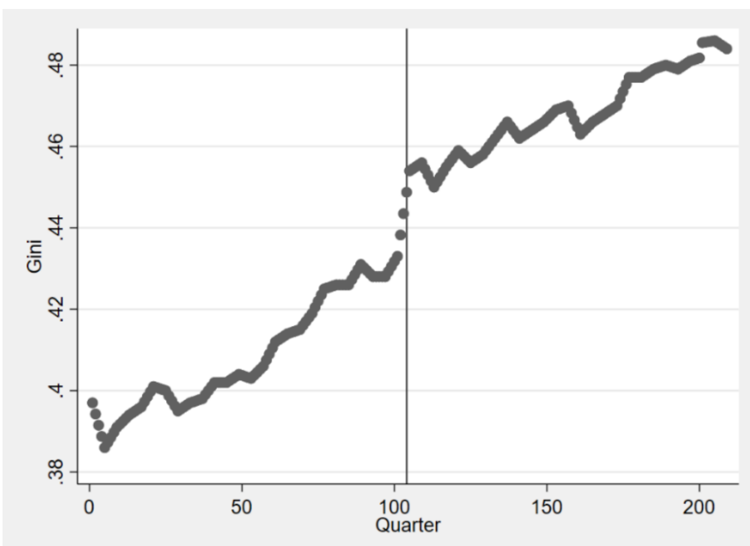
Table 1: summary statistics. Consumption, GDP and investment are reported in billions of 2012 dollars. Inflation, the interest rate, the gini coefficient and M2 growth are reported in quarterly percentage points. Lastly, productivity and wage are indices with the first quarter of 2012 being the base of 100.

Consumption, GDP and investment are reported in billions of 2012 dollars. They show high standard deviations relative to their respective means. However, looking at the figures in Appendix A this is not irregular. All series are growing around a steady trend. It also applies to both series regarding wage and productivity. They are reported as an index relative to the first quarter of 2012. Therefore, all trended series are logged, following Christiano, Eichenbaum and Evans (2005). Furthermore, inflation, interest rate and M2 growth are reported in quarterly percentages. Those series look more volatile, especially the growth rate of monies. Also, inflation and the federal funds rate peak during the first fifty quarters. It includes the 70s when high inflation and interest was a regular phenomenon. Overall, the summary statistics and figures in Appendix A display no anomalies of any kind.

Further investigation of US income inequality

As earlier stated, income inequality is a much-discussed topic. Piketty and Saez (2003) showed that US income inequality has been rising, especially after the 90s. However, to compare the effects of monetary policy shocks between high and low income inequality periods, first such periods need to be identified. Therefore, this paper uses the gini coefficient to quantify income inequality in the US. The gini coefficient is a widely used measure and is easy to obtain. This paper uses US Census (2021) data that provides yearly gini coefficients from 1967 onwards. However, to implement the VAR after splitting the sample into two periods, quarterly data is preferable. By utilizing linear interpolation the yearly data is converted to quarterly data. Below, *Figure 1* shows the interpolated data on the US gini coefficient from 1967 to 2019.

Figure 1: scatterplot of quarterly gini coefficient from 1967 to 2019.



The gini coefficient shows a clear upward trend. It supports evidence on the increasing US earnings inequality during the last half-century, as described by Heathcote et al. (2010). Moreover, there is a jump around the 104^{th} quarter. At a glance, this looks like a good point to divide the initial sample. To further quantify a potential structural break, it is tested. Although the 104^{th} quarter seems like a good candidate, the test is executed without specifying potential break dates. Table 2 shows the results below.

Test	Break date	Test statistic	P-value	Observations
Swald	104	986.6367	0.0000	209

Table 2: results of the Swald test on a structural break of quarterly reported gini coefficients.

A structural break is present at the 104th quarter making it the ideal point to split the sample. This corresponds to the first quarter of 1993. An additional advantage of the structural break is the fact that it splits the full sample into subsamples of almost identical size. However, to check whether the linear interpolation did not cause the structural break, the test is also used on the original yearly US Sensus (2021) data. The results (Appendix B) show that 1993 still divides the sample. Thus, a structural break in income inequality is present in 1993. Therefore, the initial sample will be divided into pre-1993 and post-1993. From now on, they are called the low inequality period and the high inequality period, respectively. A possible explanation for the structural break could be the Omnibus Budget Reconciliation Act of 1993. It created two new top income tax brackets and increased the minimum income tax rate. And because the poor usually only earn labor income, an increase in the income tax hurts them relatively harder. Thus, a rise in income inequality seems plausible after the tax reforms of 1993.

Identification of monetary policy shocks

To identify the effects of monetary policy shocks this paper adopts the vector autoregression approach of Christiano, Eichenbaum and Evans (2005). It is a widely used methodology to analyze the effects of shocks in a system of endogenous variables. Moreover, it isolates the effect of the shock creating a ceteris paribus impulse response analysis comparable to the simulation results. Following Christiano et al., monetary policy is assumed to follow the following relationship:

$$R_t = f(\Omega_t) + \epsilon_t$$

where R_t equals the federal funds rate, f is a linear function of the information set Ω_t and ϵ_t is a monetary policy shock. Just as in Christiano et al. (2005), I assume that the

Federal Reserve allows money supply to grow in accordance with this relation and that ϵ_t is orthogonal to Ω_t. This yields the following matrix $\boldsymbol{Y}_t$ of elements in Ω_t at time t:

$$\boldsymbol{Y}_t = [\boldsymbol{Y}_{1t,}, R_t, M_t]'$$

The elements in $\boldsymbol{Y}_{1t,}$ are, in order, real GDP, real consumption, the GDP deflator, real investment, real wage, labor productivity and the gini coefficient. They are assumed not to move contemporaneously with a monetary policy shock. R_t is the federal funds rate and the M_t is the growth rate of M2 money supply. All variables are logged, except for M_t and inflation since both variables have negative occurrences. Moreover, the lag decision is based upon the Akaike Information Criterion (AIC). Thus, the low inequality period model utilizes four lags, whilst the high inequality model uses only two lags. To test for robustness, I also estimated the high inequality model with four lags. These stand in Appendix D. They are qualitatively similar compared to the high inequality results of section 5. Thus, I prefer to use the model with the best AIC. Moreover, Appendix E shows the model equations and the AICs.

4. A simplified HANK model of McKay and Reis

This section describes a simplified version of the McKay and Reis (2016) model on automatic stabilizers in the US economy. It omits most taxes, includes further simplifications and is published alongside their full model. The simplified model has both patient and impatient households. Patient households are characterized by their full access to insure against all types of idiosyncratic risk. Contrary, impatient households have a higher intertemporal discount factor and are not able to insure against all forms of idiosyncratic risk. Note that the primary objective of the section below is to show the model. Therefore, full derivations are not present. They can be found in the according appendix of McKay and Reis (2016)

The patient household problem

Since patient households can insure themselves against all forms of idiosyncratic risk a representative household suffices with the following standard utility function,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log\ c_t - \psi_1 \frac{n_t^{1+\psi_2}}{1+\psi_2} \right]$$

where c_t is consumption, n_t is working hours, both non-negative. Moreover, β, φ_1 and φ_2 are parameters for the discount factor, the willingness to work and the Frisch labor supply elasticity, respectively. Thus the representative household chooses a bundle $\{c_t, n_t\}$ that maximizes their utility function subject to the budget constraint,

$$p_t[c_t + k_{t+1}] + b_{t+1} - b_t = p_t \left[(i_{t-1}/p_t) b_t + d_t + (1-\tau_t) w_t \bar{s} n_t + (1+r_t) k_t - \frac{\zeta}{2} \left(\frac{\Delta k_{t+1}}{k_t} \right)^2 k_t \right]$$

where b equals nominal bond holdings, k is capital, d is dividend from ownership of intermediate good firms, $\bar{s}$ is the skill-level of the patient household, w is the aggregate wage, ζ is a parameter that represents the magnitude of the quadratic cost function of capital and τ_t is a proportional tax on labor income. The left hand side represents expenditures for consumption and capital at the current price level p_t and riskless bonds. All sources of income are nominal bond returns, dividends from intermediate good firms, after-tax labor income and capital returns minus capital adjustment costs. To rewrite the budget constraint in real terms McKay and Reis (2016) define $\pi_t = p_t / p_{t-1}$ and x_{t+1} as real end-of-period savings at period t. This yields the following constraint:

$$c_t + k_{t+1} + x_{t+1} = \frac{1+i_{t-1}}{\pi_t} x_t + d_t + (1-\tau_t) w_t \bar{s} n_t + (1+r_t) k_t - \frac{\zeta}{2} \left(\frac{\Delta k_{t+1}}{k_t} \right)^2 k_t$$

The impatient household problem

In contrast to the representative patient household, there are ν impatient households. They are indexed by $h \in [0, \nu]$ such that the variable i in period t is represented as $i_t(h)$. Their utility function, stated below, is identical to that of the patient household, with the exception that $\hat{\beta} \leq \beta$.

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \hat{\beta}^t \left[\log\ c_t(h) - \psi_1 \frac{n_t(h)^{1+\psi_2}}{1+\psi_2} \right]$$

Moreover, impatient households are not able to obtain capital and obtain dividends but they can buy riskless bond. Therefore, they optimize their utility by choosing a bundle of $\{c_t(h), n_t(h), b_{t+1}(h)\}$ that follows the following budget constraint:

$$p_t c_t(h) + b_{t+1}(h) = (1 + i_{t-1}) b_t(h) + p_t[(1 - i_t) w_t s_t(h) n_t(h)]$$

Again expenditures stand on the left whilst sources of income are on the right. Also, impatient households face a borrowing constraint, $b_{t+1}(h) \geq 0$. Finally, impatient households face idiosyncratic uninsurable risk regarding their skill level $s_t(h)$. This is represented by a Markov chain and is discussed in the appendix of McKay and Reis (2014).

Final goods' producers

The final goods sector is characterized by a single representative firm facing perfect competition with the following production function:

$$y_t = \left(\int_0^1 y_t(j)^{1/\mu_t} dj \right)^{\mu_t}$$

where $\mu_t > 1$ stands for mark-up shocks and $y_t(j)$ equals the input of the jth intermediate input. Furthermore, it is a price taker regarding the final-goods price p_t. Thus, combined with zero profits and cost minimization the following conditions apply:

$$y_t(j) = \left(\frac{p_t(j)}{p_t} \right)^{\frac{\mu_t}{(1-\mu_t)}} y_t$$

$$p_t = \left(\int_0^1 p_t(j)^{1/(1-\mu_t)} dj \right)^{1-\mu_t}$$

Intermediate goods sector and price stickiness

In contrast to the final goods sector, the intermediate industry consists of a continuum of monopoly firms. Enabling them to earn profits and pay out dividends. The production function for firm j is characterized as stated below.

$$y_t(j) = a_t k_t(j)^{\alpha} \ell_t(j)^{1-\alpha}$$

Where a_t is productivity, $k_t(j)$ is capital used by firm j, $\ell_t(j)$ is effective labor and α is a parameter representing the capital share of production. The following market clearing condition applies:

$$\int_0^1 \ell_t(j)dj = \int_0^{\nu} s_t(h)n_t(h)dh + \bar{s}n_t$$

The left hand represents the sum of labor demand from all intermediate firms. It equals skill-adjusted labor supply, stated on the right hand side. Furthermore, the costs of each firm amount to the sum of wage costs, the rental rate of capital r_t, depreciation costs δ and fixed costs ξ. Thus, each intermediate firms maximizes:

$$d_t(j) \equiv \frac{p_t(j)}{p_t} y_t(j) - w_t \ell_t(j) - (r_t + \delta)k_t(j) - \xi$$

By taking into account Calvo (1983) nominal rigidities whilst setting prices the following expression for inflation can be derived.

$$\pi_t = \left(\frac{1-\theta}{1-\theta\left(\frac{p_t^*}{p_t}\right)^{1/(1-\mu)}} \right)^{1-\mu}$$

where θ equals the probability of price reversion and p_t^* being the new price after the revision date that maximizes profits. For further details regarding the derivation, see the appendix of McKay and Reis (2014).

Monetary policy and business cycle shocks

Monetary policy is determined via a simplified Taylor Rule principle that focuses solely on inflation:

$$i_t = \bar{\iota} + \phi \Delta \log (p_t) - \varepsilon_t$$

where $\phi > 1$ measures the responsiveness to the inflation gap and ε_t is a shock following an AR(1) process. Besides monetary policy shocks, two other shocks are included in the original model that also follow an AR(1) process: mark-up shocks and technology shocks. They go beyond the scope of this paper and are, thus, set to a constant.

The government

Each period the government issues a fixed amount of debt B. Therefore, the bond market clears if the following condition holds,

$$B = \int_0^{\nu} x_t(h)dh + x_t$$

where x_t equals real end-of period savings of period $t-1$. To finance the debt interest payments, the government issues a proportional labor-income tax. The representative budget constraint equals:

$$\frac{1 + i_{t-1}}{\pi_t} B = B + \tau_t w_t \left[\int_0^{\nu} s_t(h) n_t(h) dh + \bar{s} n_t \right]$$

Calibration and solution algorithm

To solve the model a large number of non-linear functions must be solved. This model uses Reiter's (2009, 2010) approach to linearizing the system around the steady state. It uses automatic differentiation. Next, the linear system is solved via Sims' (2002) algorithm.

Calibration of the model focuses on steady state income inequality represented by the gini coefficient. The target rates are the means of the different samples, presented in

Table 3. Although it is a bit crude, more advanced approaches go beyond the scope of this paper. Also, Table 3 shows the achieved gini coefficients in the steady state. For the high inequality period the target is attained, whilst the low inequality scenario approximately reaches the target.

Sample	Target gini	Gini
Low inequality	0.40963	0.40957
High inequality	0.46817	0.46817

Table 3: target and actual gini coefficient per distinct inequality period simulation.

Except for two of the initial parameters of McKay and Reis (2016), all other parameters are unchanged. Full disclosure regarding the calibration can be found in Appendix C. First, the ratio of impatient to patient households is altered from four to three. It applies to both simulations. To allow for further precise calibration I used the proportional labor-income tax. The tax rate for the low inequality period is equal to 12%, whilst the rate for the high inequality period is equal to 16.77%. From our model, it follows naturally that a higher tax rate on labor income implies higher income inequality. Impatient households, namely, only can earn income via labor or operate in the riskless asset market. Therefore, they are hurt relatively more than impatient households, who have other means of generating income.

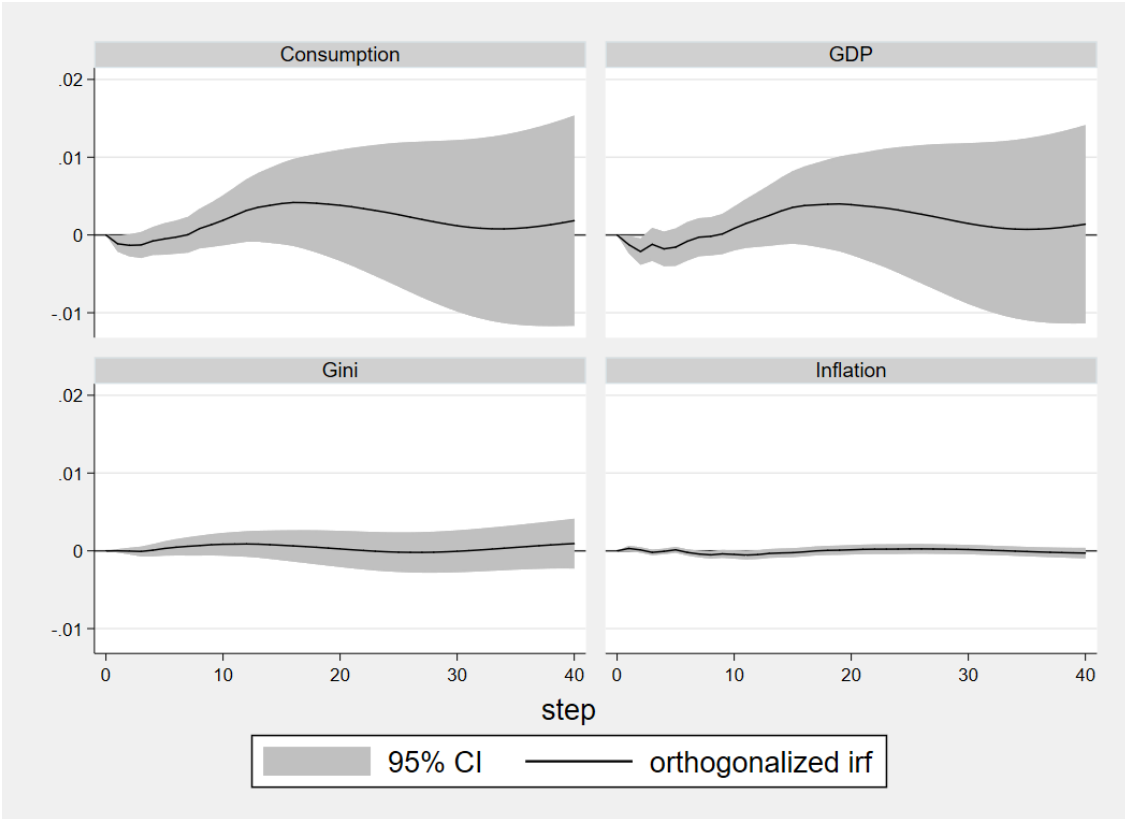
5. A comparison of HANK and empirical results

In this section, I first discuss the empirical VAR estimation results. Next, I review the model simulations outcomes. For both parts, I start by looking at the low inequality period, followed by the high inequality period. Lastly, I qualitatively compare the VAR and model simulation results concerning consumption, GDP and inflation response functions.

Low inequality VAR results

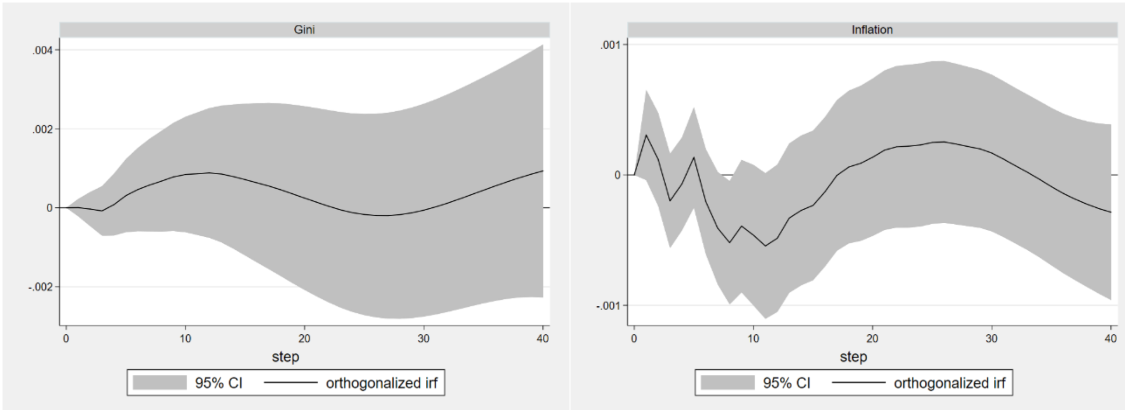
Figure 2 below shows the results of the VAR during the low income inequality period. A contractionary monetary policy shock initially has a small adverse effect on consumption and GDP. Consumption seems to be at the lowest level roughly one year after the shock and increases afterwards, up until around five years after the shock. From this point onwards consumption makes an almost sinusoidal movement. However, the confidence interval becomes increasingly wide rendering the results less and less convincing after the twentieth quarter. In contrast, GDP shows a wilder initial pattern. First, it decreases, then peaks around the third quarter after the shock, followed by a further decrease. It starts increasing again from the fifth quarter peaking again around the twentieth quarter. Afterwards, it shows a similar pattern as consumption does. Yet, also GDP has large confidence intervals. Surprisingly, the inflation does not seem to show any movement of relevant magnitude at all. In the long run, it ever so slightly decreases, but again the magnitude is negligible. Furthermore, an increase in the interest rate seems to increase income inequality in this scenario.

Figure 2: the effect of a monetary policy shock during low income inequality on consumption, GDP, inflation and the gini coefficient.



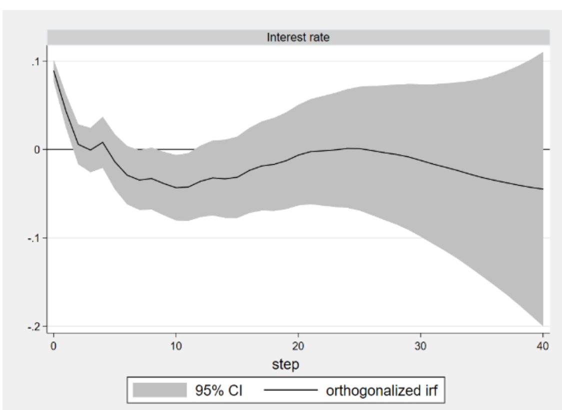
This is further shown in Figure 3. Again the effect is very small, but it shows an upward trend during the five years after the shock. Afterwards, it dips around the twenty-fifth quarter but starts rising again. Figure 3 also zooms in on inflation after the shock. First, it increases, followed by a sharp decrease. Again, the pattern repeats itself reaching the minimum around the 12th quarter. Afterwards, it gradually increases back to the pre-shock level. However, inference for both variables remains tricky since the confidence intervals quite often simultaneously lie above and below the pre-shock value.

Figure 3: the effect of a monetary policy shock during low income inequality on inflation and the gini coefficient.



Moreover, the figure below presents the response of the interest rate. It steadily decreases up until four quarters after the shock. Experiences a temporary increase, and starts decreasing afterwards until it reaches the minimum roughly two-and-a-half years after the shock. Again, the confidence interval contains the initial value often, rendering inference difficult for most of the time.

Figure 4: the effect of a monetary policy shock during low income inequality on the interest rate.



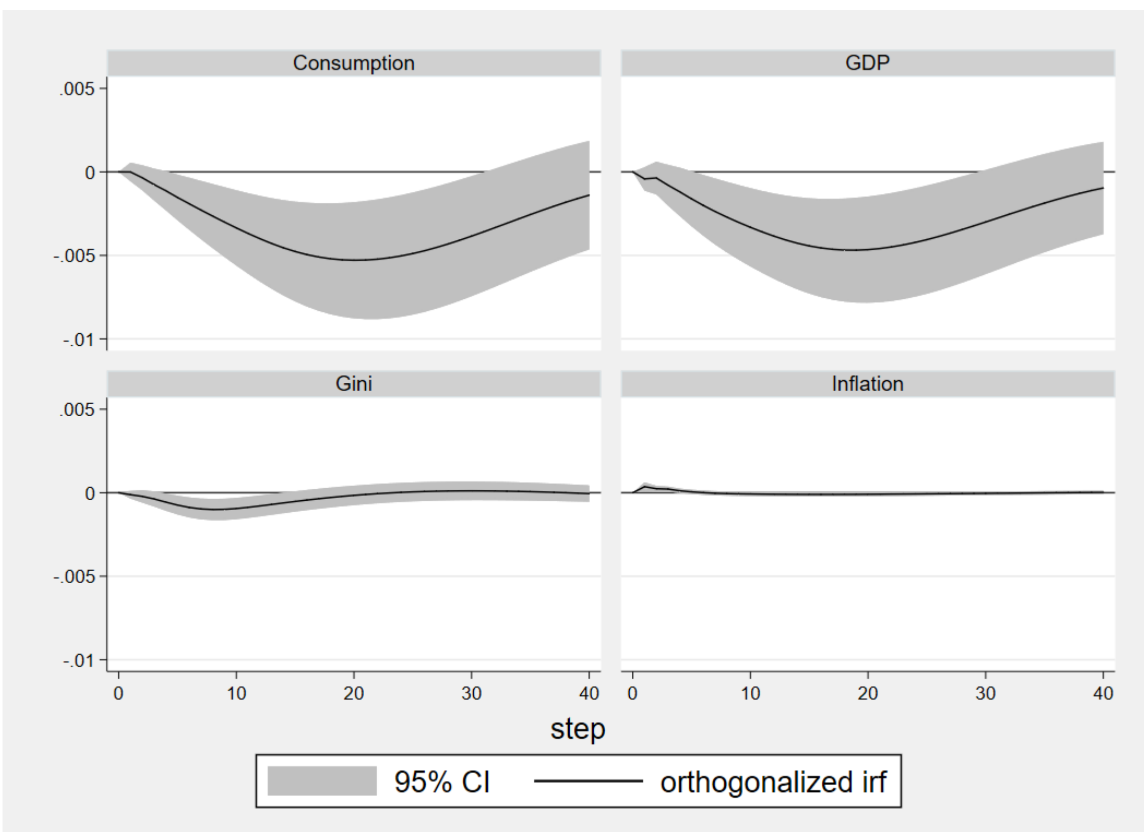
High inequality VAR results

In contrast to the low income inequality period, both consumption and GDP follow a nearly identical response function. The response functions are in line with Christiano et al. (2005)[1]. They decrease steadily reaching a minimum around five years after the shock.

[1] Note that Cristiano et al. (2005) use an expansionary policy shock. Accordingly, my results should be their mirror image.

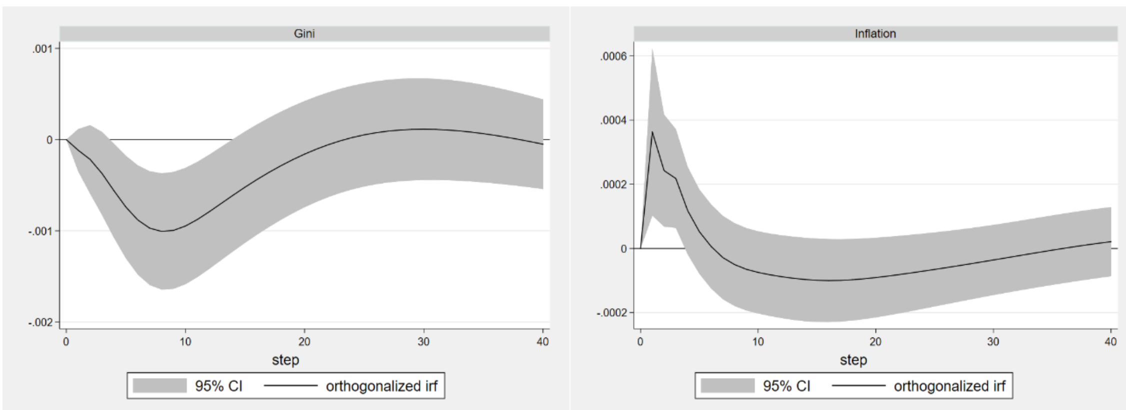
From that point onwards, both variables steadily increase until the end of the analysis. Even though the fact that the magnitude of the effects is not very large, both confidence intervals lie below the initial point for almost the entire response function. This is a clear indication that a contractionary monetary policy shock has adverse effects on consumption and GDP during periods of high income inequality. Something that cannot be said about its low inequality period counterpart. Another interesting observation is the decline of the gini coefficient after a contractionary shock. Again, the effect size is small, but the confidence interval lies below its initial state with a minimum around the seventh quarter after the shock. Subsequently, the gini coefficient rises. So, while both consumption and GDP decline in the short and medium run, income inequality decreases after a contractionary policy shock. In contrast, inflation seems to experience an increase, followed by a reversion to its initial state. However, it is not clear from Figure 5.

Figure 5: the effect of a monetary policy shock during high income inequality on consumption, GDP, inflation and the gini coefficient.



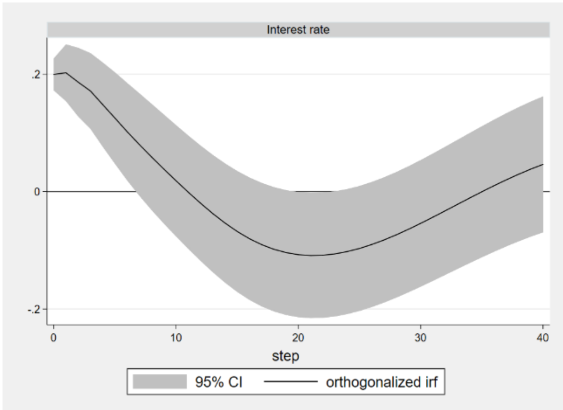
Therefore, Figure 6 zooms in on both the response functions of the gini coefficient and the inflation. Again, the gini coefficient decreases in the short and medium run. Moreover, Figure 6 clarifies the response function of inflation. Despite wide confidence intervals, it is clear that inflation initially rises. It lasts for roughly one and a half years. From then on, inference relative to the pre-shock state is difficult because the confidence interval simultaneously lies above and below zero.

Figure 6: the effect of a monetary policy shock during high income inequality on the gini coefficient and inflation.



Next, Figure 7 displays the response function of the interest rate itself during high income inequality. The function is nicely U-shaped with its minimum roughly five years after the shock. Thus, compared to the low inequality period, the transition is much smoother. Also, the initial increase is twice as large compared to its low inequality counterpart with relatively smaller confidence intervals.

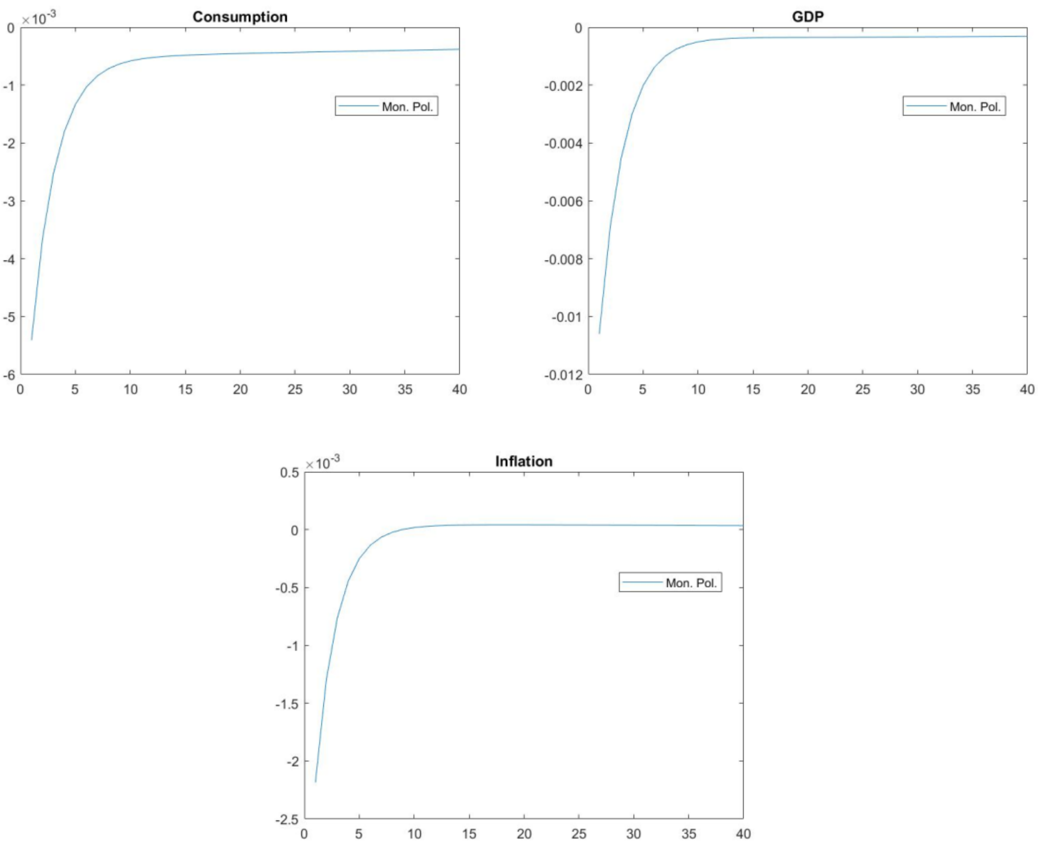
Figure 7: the effect of a monetary policy shock during high income inequality on the interest rate.



Low inequality simulation results

The results of the low inequality period simulation stand below in Figure 8. It shows the effect of a contractionary monetary policy shock on consumption, GDP and inflation respectively. All paths look relatively similar with an initial fast recovery that slows drastically after five quarters. Especially consumption does not return to the pre-shock level after more than ten years. Still, the magnitude of the effect is not very large. In contrast, inflation is back at the original level roughly two years after the shock. Overall, the tracked variables show a quite homogeneous path.

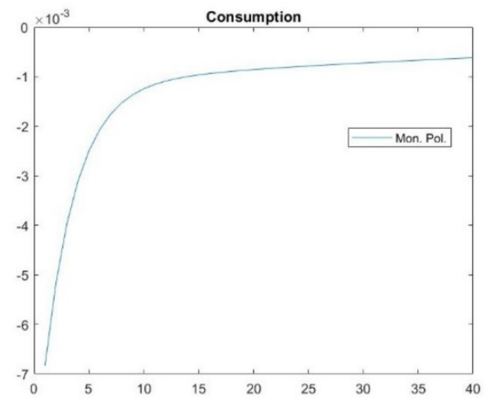
Figure 8: the simulated effects of a monetary policy shock during low income inequality on consumption, GDP and inflation.

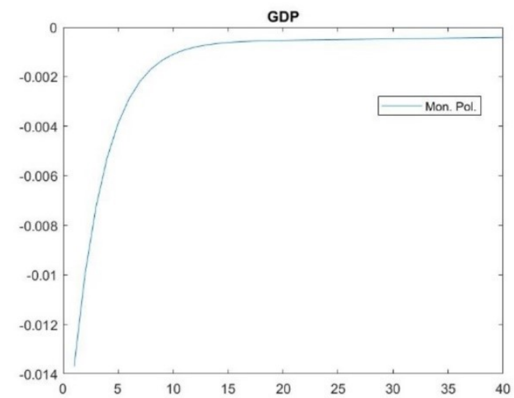


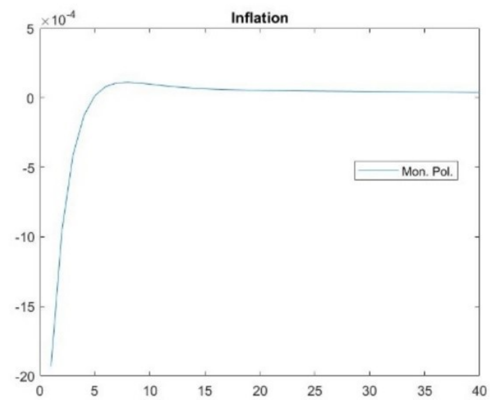
High inequality simulation results

Looking at the results of the high income inequality period simulation (Figure 9), a few differences stand out. First, consumption shows a far slower initial return. After five quarters it lags behind for almost fifty percent on the low inequality counterpart. Moreover, inflation also exhibits a completely different trend. Instead of steadily converging to the initial state, it now peaks above it around the sixth quarter. Only afterwards, it converges back down. Lastly, the curvature of the GDP response looks most similar to its low inequality counterpart. Still, it converges slower than before.

Figure 9: the simulated effects of a monetary policy shock during high income inequality on consumption, GDP and inflation.







Overall, the simulation results seem to indicate that both consumption and GDP converge slower during high income inequality, whilst inflation seems to increase faster and peak above the initial pre-shock level.

A notion before the comparison between model predictions and empirical results

With both the empirical findings and the HANK prediction of the McKay and Reis (2016) model a proper comparison can be made. First, it must be stressed that confidence intervals for most variables are quite wide. Often, it captures the pre-shock state for most of the response time. This applies to consumption and GDP in both inequality periods and to a lesser extent to the interest rate, inflation and the gini coefficient. Those variables provide relatively more certainty in the high income inequality period, as described by Figures 6 and 7.

A qualitative comparison of consumption patterns

However, with this notion settled I will look at the consumption patterns. The HANK model suggests an initial decrease with a slow but steady recovery to the initial state for both calibrations. However, the data clearly shows two distinct response functions. During high inequality, consumption decreases for almost five years after the shock before it recovers. Contrary to both model predictions and its high inequality counterpart, the response function of consumption during low inequality suggest an initial increase. Therefore, it appears that the HANK model surely can qualitatively predict better during the high income inequality period. Moreover, the model suggests a slower recovery path which the data also show. In addition, a perhaps surprising finding is that the model predictions are actually around the same size of magnitude for both variables. Concluding, the HANK model performs qualitatively better during the high income inequality period, although it underestimates the recovery speed quite a bit.

A qualitative comparison of GDP patterns

Looking at the response functions of GDP it is evident that the empirical results both suggest an initial decrease. Just like the HANK model predictions do. However, after a brief synchronous period, the empirical findings suggest an increase during low inequality, whilst it implies a further decrease during high income inequality. Furthermore, the only difference between the model predictions lies in the speed of recovery to the pre-shock state. The low inequality simulation suggesting a quicker recovery speed. Again, both simulations lie in the same order of magnitude as the empirical results. However, it is less clear to determine where the model predicts better. On the one hand, it does predict a faster recovery during low income inequality as seen in the data. However, it does not predict an increase in GDP while this does happen in the VAR response function. Yet, while the high inequality simulation can predict the fact that GDP is below its pre-shock state for almost the entire analysis, it surely predicts a different response. Moreover, the simulation results suggest immediate responses, whilst the data shows an inverted U-shape. In short, GDP does not seem to be very well approximated in both periods by this HANK model.

A qualitative comparison of inflation patterns

Lastly, the inflation response functions are compared. This time it is evident during which income inequality regime the HANK model prediction performs better. The empirical results suggest an initial increase during both periods, however, what follows is evidently divergent. During low income inequality, a wild pattern emerges that overall decreases the interest rate. It is followed up by an inverse U-shape function peaking. Clearly, the HANK prediction is completely off[2]. It predicts an initial decrease with a subsequent convergence to the pre-shock state. In contrast, the HANK prediction during high income inequality resembles its empirical counterpart a lot more. Although it also predicts an initial decrease, it also predicts a peak above the initial state. This is followed up by a steady convergence to its pre-shock level. The level of similarity is quite striking since, except for the initial decrease, it is similar to the empirical results. Again, both model predictions are in the right order of magnitude. However, as stated, the HANK model is clearly better able to predict the response function during high income inequality.

6. Conclusion and discussion

In this paper, I looked both at the empirical differences of monetary policy shocks in the US and HANK model predictions, from a simplified version of McKay and Reis (2016), between high and low income inequality. Building on top of the existing empirical literature on inequality from Piketty and Saez (2003), I show that a structural break in income inequality is present in 1993. Moreover, I use a VAR approach to identify the effects of a monetary policy shock. I find that during low income inequality a contractionary monetary policy shock hurts consumption and GDP in the short run. Contrary, both income inequality and inflation increase. However, those effects reverse in the medium term, while all variables tend to slowly revert to their pre-shock levels in the long run. In comparison, during high income inequality, a contractionary monetary policy shock hurt consumption and GDP both in the medium and the long run. Moreover,

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[2] Modelling inflation is notoriously hard. This is often called the prize puzzle, as first described by Sims (1992), which goes beyond the scope of this paper.

income inequality improves during the short and medium run, while inflation initially increases and slowly reverts to its initial state. Second, the qualitative HANK model predictions are not able to predict consumption very accurately. Still, the simulated response function during high income inequality is a better fit compared to the data. Also, it is evident that the HANK model performs poorly on GDP during high and low inequality. Moreover, the model predictions do not fare well for inflation during low income inequality. However, it quite accurately predicts the response function of inflation during high income inequality. On a final positive note, the model predictions consequently predict in the right order of magnitude.

However, there are some caveats present. First, the model by McKay and Reis (2016) uses a very simplified monetary policy rule without the focus on the output gap. It might not be unrealistic for the European Central Bank or the Federal Reserve (FED) during its Voeckler regime. However, usually, the FED employs a double mandate, focusing both on price and output stability. Consequently, it could have played a role in the ambiguous results concerning GDP. Another important notion is the wide confidence intervals of the VAR response function. As stated earlier, it hampers inference because the confidence intervals contain the pre-shock state. This resulted in conclusions that are less certain which is not beneficial to the overall credibility. Furthermore, I solely look to income inequality. However, income inequality is only a part of inequality. Thus, it would be better to try and include wealth inequality in a more comprehensible analysis. Moreover, I use a relatively old VAR approach. While Christiano et al.'s (2005) method is highly praised, it is a bit outdated. And a few studies already suggested some improvements. For instance, Carlstrom, Fuerst and Paustian (2009) show that standard Choleski assumptions can easily lead to distortions such as price puzzles. Nonetheless, this study should perhaps more be seen as an exploratory exercise.

Thus, based on this research it would be interesting to further explore the discussed issues. It would, for instance, be very interesting to apply an improved VAR methodology and compare this to a model that allows for an endogenous and trackable gini coefficient.

This would allow for an even more unbiased comparison because this paper uses different tax rates to accomplish it. Another interesting topic would be to explore the effects of wealth inequality and potential differences in monetary policy effects. Especially because wealth is often directly related to interest, via share or bond prices.

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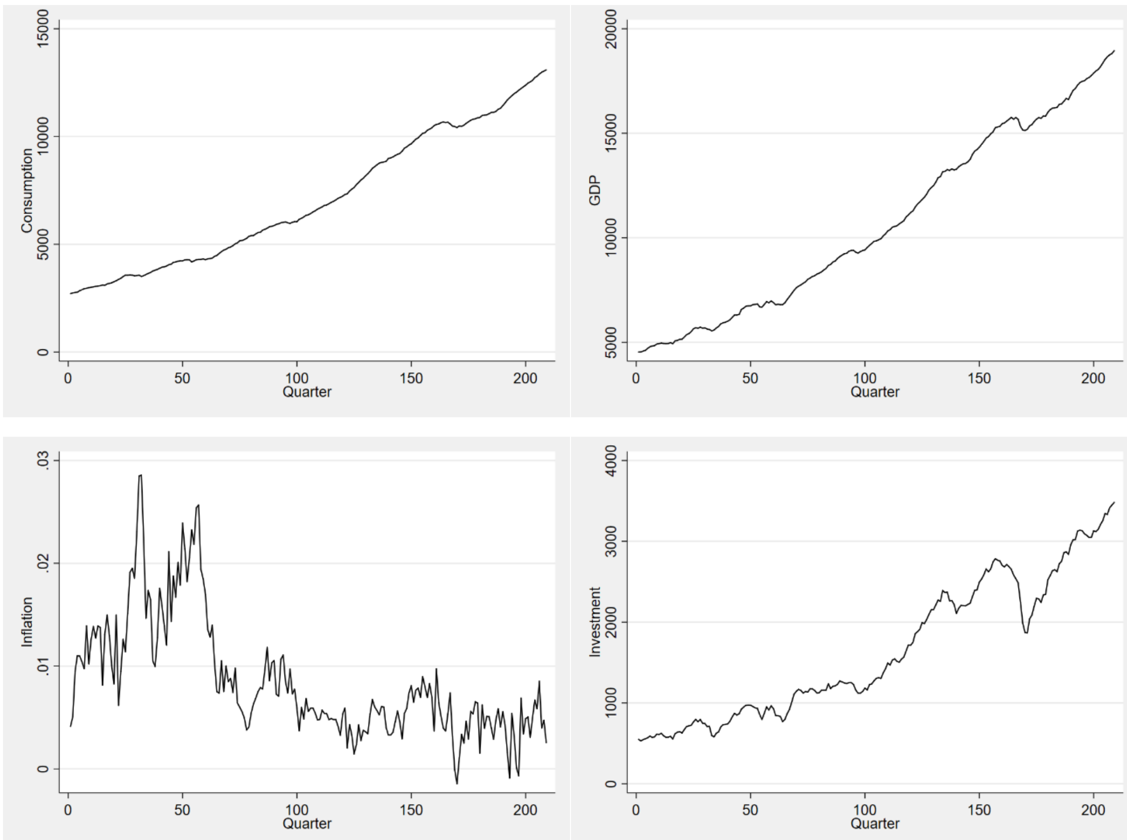
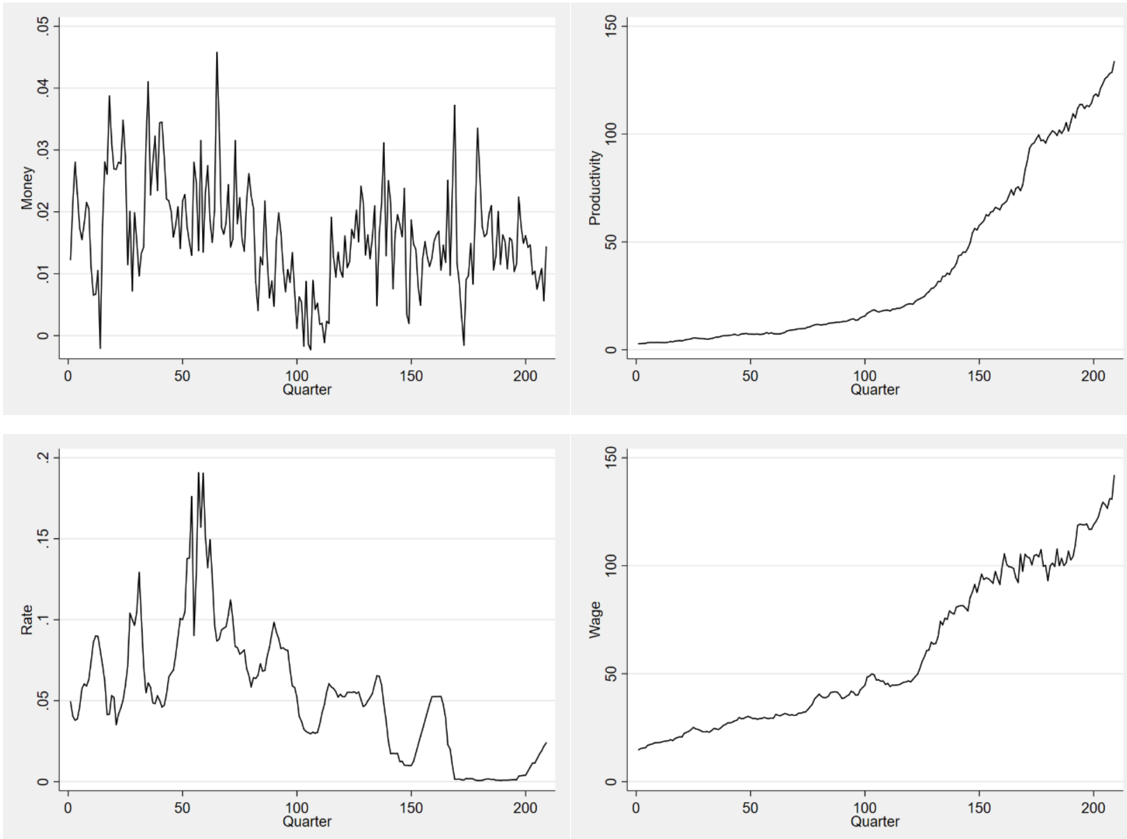
Appendix A. Figures all series

Figure 10: Quarterly trend of respectively, consumption, GDP, inflation, investment, M2 growth, productivity, the interest rate and wage, from 1967 to 2019.



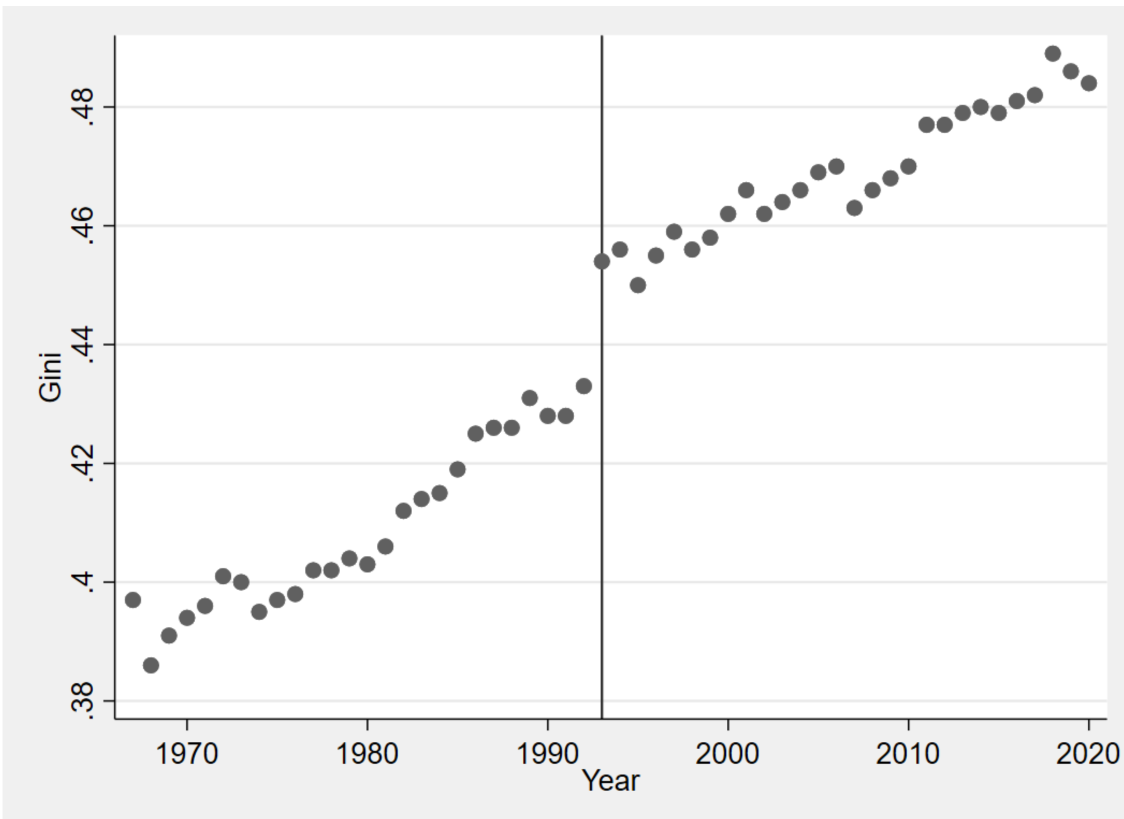

Money
0
.01
.02
.03
.04
.05
Productivity
0
50
100
150
Rate
0
.05
.1
.15
.2
Wage
0
50
100
150
0
50
100
150
200
Quarter

Appendix B. Structural break yearly gini coefficient

Test	*Break date*	*Test statistic*	*P-value*	*Observations*
Swald	1993	189.3133	0.0000	53

Table 4: results of the Swald test on a structural break of yearly reported gini coefficients.

Figure 11: Scatterplot of yearly gini coefficient from 1967 to 1993.



Appendix C. Calibration of all initial parameters

Symbol	*Parameter*	*Value low inequality*	*Value high inequality*
$\hat{\beta}$	Imp. household discount factor	0.978961862738	0.978961862738
β	Pat. household discount factor	0.988830128237	0.988830128237
σ	Standard risk aversion	1	1
φ_1	Labor supply/willingness to work	19.6855103766	19.6855103766
φ_2	Frisch labor supply elasticity	2	2
μ	Gross mark-up	1.2	1.2
θ	Price stickiness	2/7	2/7
ξ	Fixed costs	0.57528560756	0.57528560756
α	Capital share	0.232	0.232
δ	Depreciation of capital	0.0114	0.0114
ζ	Investment adjustment cost	6	6
τ	*Proportional labor tax*	*0.12*	*0.1677*
ϕ	Interest rule on inflation	1.55	1.55
ν	Imp. households per pat. household	3	3
$\bar{s}$	Skill level pat. household	3.71838356684	3.71838356684
ρ_z	Autocorrelation tech. shock	0.75	0.75
σ_z	St. dev tech shock	0.002936169743355	0.002936169743355
ρ_m	Autocorr. mon. policy shock	0.62	0.62
σ_m	St. dev mon. policy shock	0.003533607840688	0.003533607840688
ρ_p	Autocorr. mark-up shock	0.85	0.85
σ_p	St. dev mark-up shock	0.1	0.1

Table 5: calibration all model parameters for low and high income inequality simulation respectively.

Appendix D. Qualitative robustness check high inequality VAR with 4 lags

Figure 12: the effect of a monetary policy shock during high income inequality on consumption, GDP, inflation and the gini coefficient given 4 lags.

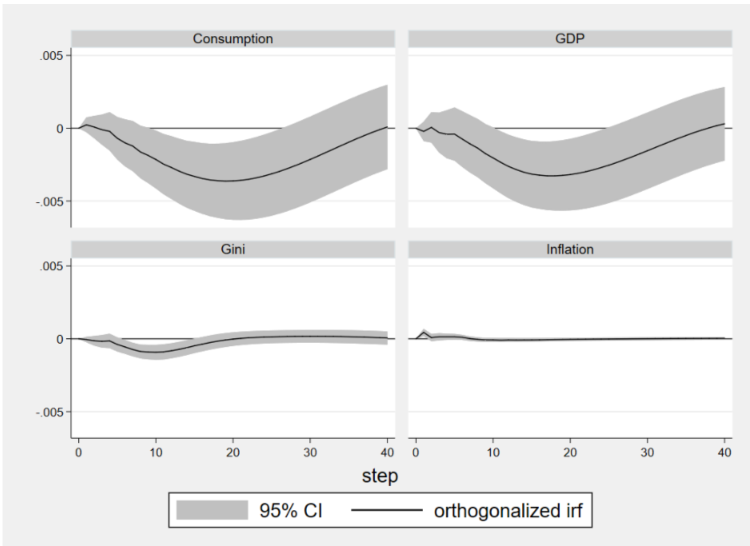
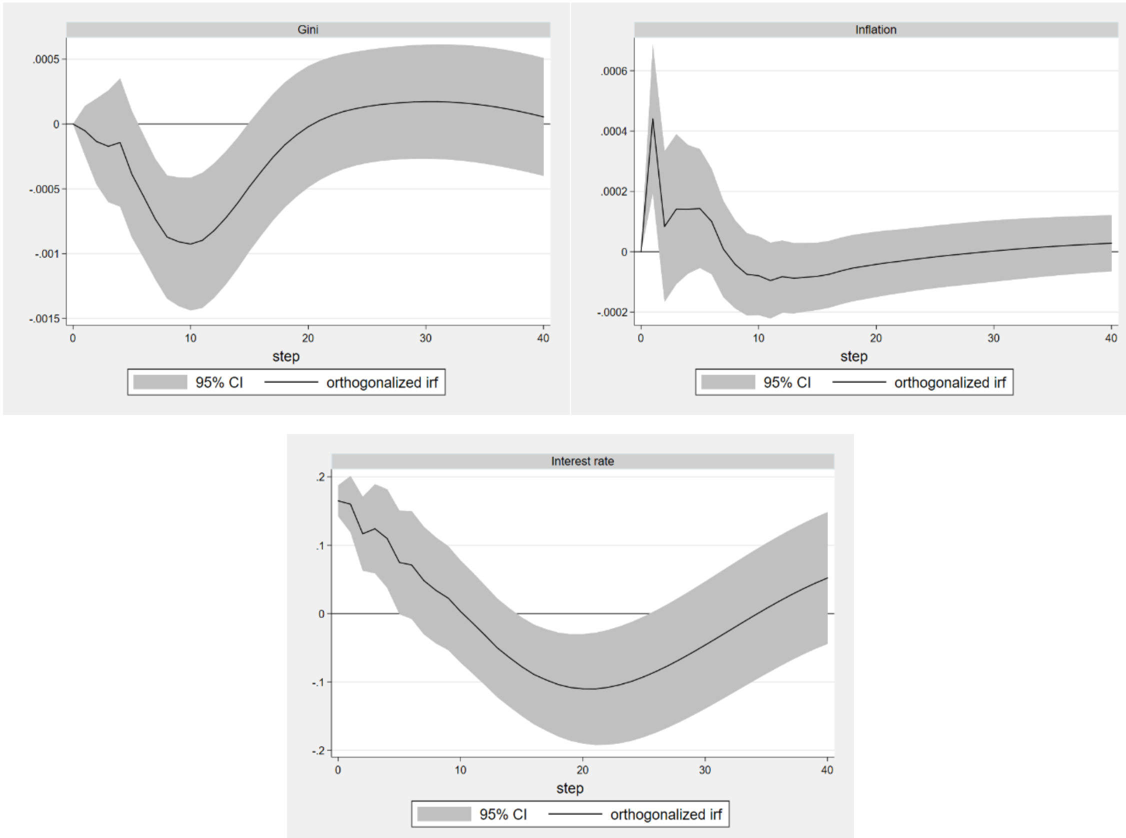


Figure 13: the effect of a monetary policy shock during high income inequality on inflation, the gini coefficient and the interest rate given 4 lags.


Gini
.0005
0
-.0005
-.001
-.0015
0
10
20
30
40
step
95% CI
orthogonalized irf
Inflation
.0006
.0004
.0002
0
-.0002
0
10
20
30
40
step
95% CI
orthogonalized irf
Interest rate
.2
.1
0
-.1
-.2
0
10
20
30
40
step
95% CI
orthogonalized irf

Appendix E. Lag selection and VAR model specifications

Lags	*AIC low inequality VAR*	*AIC high inequality VAR*
0	-37.4541	-38.5027
1	-55.9968	-58.3347
2	-56.6558	-59.5174*
3	-56.3008	-59.3197
4	-56.6731*	-58.9883

Table 6: AIC values of both VARs with 0, 1, 2, 3 or 4 lags, respectively. The number of observations for the low inequality sample is 100. The number of observations for the high inequality sample is 101.

As Table 6 shows, four lags provides the best fit for the low inequality VAR. Moreover, two lags is optimal for the high inequality VAR. Both model equations stand below, first the low inequality model, second the high inequality model.

$$\boldsymbol{Y_t} = \sum_{i=1}^{4} \boldsymbol{A_i Y_{t-i}} + \boldsymbol{C\varepsilon_t} \ (1)$$

$$\boldsymbol{Y_t} = \sum_{i=1}^{2} \boldsymbol{A_i Y_{t-i}} + \boldsymbol{C\varepsilon_t} \ (2)$$

In accordance with the AICs, the lag length is shown by the upper index of the summation. The parameters $\boldsymbol{A_i}$ are estimated using ordinary least squares regression. Moreover, the $\boldsymbol{C}$-matrix is a 9x9 lower triangle matrix with the gini coefficient being the 7th term and the interest rate the 8th. Lastly, $\boldsymbol{\varepsilon_t}$ equals the error terms.