Quantifying the Fiscal Channel of Monetary Policy*

Frederik Kurcz[§]

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Abstract

In business-cycle models the effects of monetary policy depend on the fiscal reaction to interest rate changes. This paper presents new evidence on the effects of U.S. monetary policy on fiscal policy instruments and subsequently estimates a Heterogeneous Agent New Keynesian model with flexible fiscal feedback rules. I find that fiscal policy responds to monetary-induced output contractions with debt-financed, countercyclical tax and transfer policies, amid a gradual decline in spending to accommodate the debt increase. The model implies that monetary policy unopposed by a business-cycle stabilization motive of fiscal policy would be roughly 50% more contractionary.

Keywords: Macroeconomic Policy, HANK, Monetary Fiscal Interaction, Impulse Response Matching

JEL Codes: E21, E52, E60, E63

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[§]DIW Berlin, Berlin School of Economics, and Free University Berlin. Contact: Anton-Wilhelm-Amo 58, 10117 Berlin, fkurcz@diw.de. Website: https://frederik.kurcz.de

1 Introduction

Heterogeneous Agent New Keynesian (HANK) models significantly changed our understanding of the relative importance of monetary transmission channels. This theoretical reappraisal highlighted a strong dependence of the effects of monetary policy on the fiscal response to interest rate changes (Kaplan, Moll and Violante, 2018). Different assumptions on financing higher interest rates on government debt turn out to be one of the most important determinants of the aggregate effects of monetary policy — a theoretical insight that is not confined to models featuring heterogeneity.[1] As a result, any exploration of monetary policy in New Keynesian models depends crucially on the set of fiscal rules governing the instruments at the fiscal policymaker's disposal. This raises the question: How does fiscal policy react systematically to interest rate changes, and how does the fiscal response shape the effects of monetary policy quantitatively?

I address this question by presenting new evidence on the dynamic causal effects of U.S. monetary policy on fiscal variables utilizing vector autoregressions. The estimated impulse response functions then serve as the empirical moments to estimate a HANK model with rich household heterogeneity, which is augmented by flexible feedback rules for government spending and income taxes. Importantly, the fiscal block of the model is empirically disciplined by the evidence of the fiscal reaction to monetary policy via an impulse response function matching estimator. As a result, this model allows, via a series of counterfactuals, the characterization and quantification of the fiscal channel of monetary policy.

I find that, first, contractionary monetary policy shocks lead to an expansionary fiscal reaction that is financed with debt. Together with the costs incurred via the higher real interest rate, the expansionary fiscal reaction leads to a dual strain on the government budget. The income tax rate falls with a delay of around a year, cyclical transfers increase, and government spending displays a slow, gradual decrease. Second, the estimated fiscal feedback rules in the HANK model reveal that the government is not systematically responding to the interest rate. Instead, transfers and taxes exhibit automatic stabilizer behavior, and the income tax rate responds countercyclically to economic conditions. Government spending is the primary fiscal instrument for the eventual debt consolidation, but is insensitive to economic conditions. Third, the total systematic fiscal response shapes the aggregate effects of monetary policy substantially by partially offsetting monetary-induced output losses. A counterfactual exercise shows that without the fiscal stabilization of economic activity, the effects of monetary policy would be roughly 50% more contractionary. This implies that the fiscal channel renders the effects of monetary policy dependent on the fiscal response, in the same vein as the fiscal multiplier is known to be dependent on the monetary reaction.

[1] See Caramp and Silva (2023) for the dependence of the representative agent New Keynesian model on the fiscal reaction and the related discussion in Kaplan (forthcoming).

More in detail, the key objects of interest for the characterization of a fiscal channel of monetary policy are the systematic fiscal policy rules describing the behavior of the government. To bring fiscal variables to bear on the estimation of these structural relationships, in the first part of the paper, I analyze the effects of structural monetary shocks on all fiscal variables relevant for the conduct of fiscal policy and the government's budget constraint. The empirical approach is to use state-of-the-art high-frequency Federal Reserve monetary surprises by Bauer and Swanson (2023*b*) in a mixed-frequency vector autoregressive (VAR) model that combines monthly macroeconomic data with quarterly fiscal variables.

A contractionary monetary policy shock increases U.S. outstanding debt strongly and persistently, the tax rate drops sizably after roughly a year, and government spending starts to decrease with a delay of about two years. Unemployment and safety-net transfers increase, in line with the unemployment rate. By exploiting an average personal income tax rate measure that by construction fixes the tax base and therefore isolates tax rate changes, the results show that the tax burden falls both due to automatic stabilization from progressive income taxation and due to tax policy action after an interest rate hike. In addition, I find that federal interest rate payments increase only after about three to four years after a surprise interest rate increase, suggesting that the direct effect of having to finance higher nominal interest rate costs does not play a first-order role in the fiscal channel of monetary policy. Instead, the decline in the price level increases the real debt burden sizably. Moreover, as an external validation robustness exercise, I show that the documented U.S. fiscal response is remarkably similar to an aggregate demand shock (using the "Main Business-Cycle shock" by Angeletos, Collard and Dellas (2020)). This evidence supports the notion that fiscal policy responds not to the higher interest rate itself, but to its macroeconomic consequences. In fact, even though the interest rate declines in response to the contractionary demand shock, federal interest payments increase after some time, in line with the debt increase.

With the empirical impulse response functions at hand, in the second part of the paper, I estimate flexible fiscal policy feedback rules embedded in a dynamic stochastic general equilibrium (DSGE) model that match the patterns in the data. This approach yields a full specification of systematic fiscal policy by revealing the roles played by each fiscal instrument in debt servicing, the pace of debt repayment, and the reaction to economic conditions such as output, inflation, and the interest rate. Next to providing parameter estimates of the fiscal rule coefficients, that are of interest in and of themselves, the estimated model can be used to assess how the fiscal policy response shapes the aggregate effects of monetary policy via counterfactual analysis. For this purpose, it is crucial that the model delivers a realistic description of both the transmission of monetary policy, as well as the effects of fiscal policy. Heterogeneous Agent New Keynesian models made important advances in this regard, with Kaplan, Moll and Violante (2018) and Auclert (2019) showing that HANK models imply very different monetary transmission than the previous representative agent literature.[2] Furthermore, Kaplan and Violante (2014), Kaplan and Violante (2022), and Auclert, Rognlie and Straub (2024) argue that this class of models is uniquely suited to the analysis of fiscal policy by featuring high intertemporal marginal propensities to consume (MPCs), wealthy hand-to-mouth agents, and matching cross-sectional data on MPCs and more generally the income and wealth distribution in the U.S. The latter is a necessary condition to study how the fiscal channel shapes and alters the redistributional consequences of monetary policy. Consequently, a canonical medium-scale two-asset HANK model (as in Bayer, Born and Luetticke (2023, 2024)) serves as the laboratory for the analysis of the fiscal channel of monetary policy. I compare it to the corresponding estimated Representative Agent New Keynesian (RANK) model and find that it does not match key moments relevant for fiscal policy.

To estimate the parameters governing the dynamics of the model, I employ Bayesian impulse response function (IRF) matching (Christiano, Trabandt and Walentin, 2011), the properties of which fit the purposes of this analysis better than likelihood-based full-information estimation, for three reasons. First, since the main interest lies in the propagation of a single shock, IRF-matching sidesteps the need to explicitly model all structural shocks and their exogenous stochastic processes driving the business cycle, limiting potential misspecification (see Chari, Kehoe and McGrattan (2009)). Second, Fernández-Villaverde, Rubio-Ramírez and Schorfheide (2016) emphasize that even if misspecification is a concern, IRF-matching is more robust in its presence, at the cost of efficiency. Third, there is a broad consensus that U.S. monetary policy experienced a significant change in its systematic conduct in the early 1980s, rendering the sample short.[3]

The parameter estimates reveal that the increase in debt is repaid very slowly, and mainly by a decrease in government spending. This informs the crucial debt-adjustment parameter in the monetary analysis literature, that for lack of empirical evidence had to usually be calibrated, based often on descriptive statistics. Moreover, fiscal policy reacts strongly countercyclically to output deviations due to automatic stabilizers and endogenous adjustments of the tax burden. In contrast, there is no systematic government spending reaction to output, and both instruments only respond weakly to inflation. Allowing the fiscal policy rules to react to the interest rate directly yields coefficients close to zero. The estimated fiscal rule parameters are robust: carrying out the same identification strategy instead with an aggregate demand shock yields fiscal parameter estimates that are very similar.

Finally, the model is used as a laboratory to quantify the fiscal channel of monetary

[2] The new transmission mechanisms, e.g. on indirect effects outweighing direct effects, has since found empirical support, see Holm, Paul and Tischbirek (2021), Ampudia et al. (2018), and Slacalek, Tristani and Violante (2020).

[3] See, e.g., Bernanke and Mihov (1998), Clarida, Gali and Gertler (2000), and Bianchi (2013).

policy. In the absence of a business-cycle stabilization motive of fiscal policy, the (statutory) tax rate does not decline after an interest rate increase. As a consequence, output drops by roughly 40% more than it would under the estimated fiscal policy response. Automatic income stabilization due to progressive income taxation additionally dampens the output response by 10%. Monetary transmission to inflation is similarly counteracted, but to a lesser extent. The counterfactual results additionally highlight the prominent role that indirect (general equilibrium) forces play in the monetary transmission mechanism via income and consumption: estimates of the effects of monetary policy understate them, since they are on average counteracted by the fiscal stabilization. Moreover, the comparison to RANK shows that although the aggregate monetary effects are similar in HANK vs. RANK, quantitative scenario analyses of monetary policy necessitate a model that can match fiscal policy moments.

The result that the monetary shock is counteracted by a stabilization motive of the fiscal authority resonates with the analogous case, well-known in the literature: fiscal stimulus, by increasing output and inflation, is counteracted by monetary policy operating a standard Taylor rule (see, e.g., Christiano, Eichenbaum and Rebelo (2011), Woodford (2011), Cloyne, Jordà and Taylor (2023)). As a consequence, the fiscal multiplier is state-dependent on the monetary reaction: if monetary policy is unresponsive, fiscal multipliers are much higher (Hack, Istrefi and Meier, 2023). By the same token, the fiscal channel can only operate depending on the fiscal capacity of the government, which is put under a dual strain after higher interest rates: the government needs to consolidate a higher real debt burden as well as cope with lower tax revenues from stabilizing some of the output loss. Thus, the effects of monetary policy are equally dependent on the fiscal "space" to do so.

Related Literature. This paper is related to four strands in the literature. First, by studying a type of monetary-fiscal interaction, it naturally stands in relation to the literature studying "active" and "passive" monetary and fiscal policies, as per Leeper (1991), and the associated Fiscal Theory of the Price Level, further developed in e.g. Sims (1994), Woodford (1995), and Cochrane (1998), among many others. For the post-1984 U.S. sample considered here, the evidence compiled in the literature on monetary-fiscal interaction suggests that the U.S. was in an active-monetary regime (see, e.g., Lubik and Schorfheide (2004), Bianchi and Ilut (2017), Leeper, Traum and Walker (2017)). Therefore, the analysis in this paper focuses on that regime, meaning that the central bank stabilizes inflation and fiscal policy passively balances the government budget. Since Bianchi and Melosi (2017) present evidence for a switch in the policy regime at the Zero Lower Bound (ZLB), the results presented below are verified to be robust to the exclusion of the ZLB episode.

Second, there is a large and burgeoning literature revisiting the interconnectedness of monetary and fiscal policy since the adoption of HANK models, in which Kaplan, Moll and Violante (2018) showed that it is crucial to take fiscal policy rules into account for monetary transmission.[4] Alves et al. (2020), Bellifemine, Couturier and Jamilov (2025), and Auclert, Rognlie and Straub (2020) study theoretically how the fiscal repercussions that interest rates exert on debt-servicing costs influence monetary transmission. Mangiante and Meichtry (2022) highlight the role of fiscal transfers for monetary policy, while Andreolli (2021) finds the maturity structure of government debt to be an important determinant. Campos et al. (forthcoming) argue that permanent changes in the stock of public debt affect the natural interest rate, thereby impinging on how monetary policy should be set. More generally, Caramp and Silva (2023) and Kaplan (forthcoming) emphasize that the standard New Keynesian models, even with passive fiscal policy, predict that higher interest rates can only lower inflation if followed by a fiscal contraction. Finally, Angeletos, Lian and Wolf (2026) investigate under which conditions fiscal policy supports monetary policy in achieving its mandate. Relative to all these theoretical insights, the contribution of this paper lies in providing the empirically disciplined fiscal reaction as an important benchmark, by estimating and characterizing the fiscal behavior via estimated feedback-rules that have been observed on average in the U.S. post-Volcker sample.

Third, this paper furthermore contributes to the literature on empirical evidence on the reaction of fiscal variables to monetary policy shocks. Sterk and Tenreyro (2018) study the debt response to monetary policy and Mangiante and Meichtry (2022) the transfer response. In contemporaneous work, Bouscasse and Hong (2023) and Breitenlechner, Geiger and Klein (2024) study more generally fiscal responses and conclude that the government "does not react", or stays passive, and mainly lets debt adjust. I find that the issuance of new debt does not prove to be the full picture of the fiscal response, but in addition, the fiscal authority is actively counteracting the monetary disturbance. Moreover, these empirical papers do not characterize systematic fiscal policy rules and are thus silent on the motives behind the government actions and on informing the theoretical modeling of fiscal policy. Finally, with an estimated, micro-founded model I can ask counterfactual questions that are infeasible empirically, such as about the automatic stabilizing effects of progressive taxation as part of the fiscal channel, as carried out below.

Fourth, this paper is additionally connected to the literature on estimating systematic fiscal policy rules, sparked by the seminal contribution of Bohn (1998). A range of papers uses full-information likelihood based methods to estimate DSGE models and associated fiscal policy rules, such as Leeper, Plante and Traum (2010) (who estimate a neoclassical growth model), Kliem and Kriwoluzky (2014), Bayer, Born and Luetticke (2024), and Bilbiie, Primiceri and Tambalotti (2023). However, all of these papers employ full-information estimation

[4] HANK models are a natural study-ground for these questions since they are able to match fiscal multipliers (Auclert, Rognlie and Straub, 2024). However, any model that breaks Ricardian Equivalence and features realistic MPCs can speak to these issues and have been applied in this context, e.g. models featuring two agents, overlapping generations, bonds-in-utility, or learning as well as other behavioral frictions.

on aggregate time series, mostly on the full post-WWII U.S. sample. This leaves these papers open to the misspecification and weak identification concerns raised by Chari, Kehoe and McGrattan (2009) and Fernández-Villaverde, Rubio-Ramírez and Schorfheide (2016), as well as possible regime changes in policy during the sample. Caldara and Kamps (2017) show how to recover systematic fiscal policy rules from structural VARs and find an important output stabilization coefficient for taxes, in line with my results. Corsetti, Meier and Müller (2012) focus on the systematic conduct of government spending, providing evidence that higher debt levels are financed by below-trend government spending, consistent with my results. The contribution to this literature is to bring a full set of impulse responses of fiscal variables to bear on the estimation of fiscal feedback rules, and analyze their consequences specifically for monetary policy, which is not a focus in any of the aforementioned papers.

Outline. The paper is organized as follows. Section 2 briefly lays out more precisely the objects of interest and the identification strategy. Next, Section 3 presents the empirical time series model and the estimation of the fiscal response to identified monetary policy shocks. Turning to the theoretical model to be estimated, Section 4 describes the HANK model and Section 5 its estimation and estimation results. Finally, Section 6 discusses the fiscal response through the lens of the model and quantifies the fiscal channel. Section 7 concludes.

2 A General Model of Both Monetary and Fiscal Policy

The literature on monetary policy theory routinely analyzes models of the general form

$$\boldsymbol{x}_t = \boldsymbol{A} E_t[\boldsymbol{x}_{t+1}] + \boldsymbol{B}\boldsymbol{\varepsilon}_t \tag{1}$$

$$r_t = \theta_\pi \pi_t + \theta_Y y_t + \varepsilon_t^R, \tag{2}$$

where $\boldsymbol{x}_t$ denotes the vector of endogenous variables (in percent deviations from steady state), including at least output and inflation $(y_t, \pi_t)'$, and $\boldsymbol{\varepsilon}_t$ is a vector of exogenous stochastic processes. Equation (1) is the stereotypical log-linearized non-policy block of a micro-founded model of monetary policy transmission. It nests both simple two-equation textbook New Keynesian models as well as medium-scale HANK models and is supplemented with a standard Taylor rule for the nominal (net) interest rate r_t. With regard to fiscal policy in monetary analysis (in an active monetary regime), the Representative Agent New Keynesian (RANK) literature mostly focused on a useful benchmark case exploiting Ricardian Equivalence and the assumption of lump-sum transfers to balance the government budget constraint, often not even modeling a fiscal block explicitly.[5] Nonetheless, even in RANK models with Ricardian

[5] In the textbook treatment of Galí (2015), fiscal policy is not mentioned, nor is fiscal policy a part of influential medium-scale models for policy analysis such as Smets and Wouters (2007).

Equivalence and lump-sum transfers, Caramp and Silva (2023) have recently shown that the fiscal adjustment creates a wealth effect that substantially shapes the consumption response after a monetary policy shock. Moreover, models without Ricardian Equivalence (due to, e.g., more than one agent, finite lives, or imperfect foresight, among others) usually feature a high marginal propensity to consume (MPC), a robust pattern in the data. In these types of business-cycle models, the analysis of monetary policy not only crucially depends on assumptions for fiscal policy rules, it is precisely the high MPCs that make the fiscal policy reaction in the monetary policy transmission mechanism potent.

Therefore, an explicit fiscal block needs to feature in the model. This means taking a stance on how the government conducts systematic fiscal policy for taxes, government spending, which instrument is used for debt consolidation, and how quickly debt is repaid. As a result, for the fiscal channel of monetary policy, the parameterizations of these fiscal rules are the key objects of interest. Equations (3) - (4) describe general feedback rules for the main instruments of fiscal policy, the tax rate τ_t, and government spending g_t:

$$\tau_t = \gamma_Y^{\tau} y_t + \gamma_B^{\tau} b_t \tag{3}$$

$$g_t = \gamma_Y^{G} y_t - \gamma_B^{G} b_t \tag{4}$$

The inclusion of economic conditions in the form of output y_t captures a business-cycle stabilization motive of fiscal policy. These feedback rules are still parsimonious, since other input arguments could in principle be possible, which will be investigated in later sections. Even so, most models of monetary policy feature $\gamma_Y^{\tau} = \gamma_Y^{G} = 0$ and either $\gamma_B^{\tau} > 0, \gamma_B^{G} = 0$, or vice versa. In order to obtain a full description of fiscal policy and study how systematic fiscal feedback rules shape the monetary transmission mechanism, the goal will be to estimate the parameters of the fiscal policy rules.

The empirical strategy to identify the parameters of the fiscal rules is to use exogenous variation in monetary policy. The identification strategy is analogous to using supply-side shocks that shift the supply curve to trace out and identify the slope of a demand curve: by using exogenous changes in interest rates that move output, inflation, and government debt, we can elicit the endogenous response of fiscal policy. This strategy hence involves estimating impulse response functions as the key empirical moments in the data, which will be carried out in the next section. Since monetary policy shocks are usually found to drive only a small share of volatility in macroeconomic aggregates, using monetary shocks as instruments might raise weak instrument concerns. Therefore, as a robustness check, a strong instrument — by construction — for moving macroeconomic variables is employed, utilizing the "Main Business-Cycle" shock by Angeletos, Collard and Dellas (2020).

With empirical impulse response functions at hand, the non-policy block of the model will be completely specified by deriving equilibrium relations from a micro-founded model of monetary policy transmission. The parameters governing the dynamics of the model (1)–(2) as well as the description of fiscal policy (3)–(4) can then be estimated by impulse response matching (Christiano, Eichenbaum and Evans, 2005). The key innovation of this model of both monetary and fiscal policy is thus disciplining systematic fiscal policy empirically, at the same time as quantitatively matching the effects of monetary policy.

3 Empirical Evidence on the Fiscal Response to Monetary Policy

The goal of this section is the systematic analysis of effects of monetary policy on all fiscal variables relevant for the government budget constraint and fiscal policy. The resulting empirical impulse response functions provide a complete picture of the fiscal response to a monetary policy shock and constitute the macroeconomic moments that are the key input in the estimation of the structural micro-founded model in Section 4. Therefore, next I describe the general time series framework, model specification, and identification, before presenting the empirical results. Robustness results follow at the end.

3.1 Time Series Framework

I assume that the data generating process for the endogenous variables $\boldsymbol{y}_t = (y_{1,t}, \ldots, y_{n,t})'$ belongs to the general structural vector moving average (SVMA) model class

$$\boldsymbol{y}_t = \sum_{l=0}^{\infty} \boldsymbol{\Theta}_l \boldsymbol{\varepsilon}_{t-l}, \tag{5}$$

where $\boldsymbol{\varepsilon}_t$ is the unobserved white noise vector of exogenous fundamental shocks $\boldsymbol{\varepsilon}_t \sim \mathrm{WN}(\mathbf{0}, \boldsymbol{I}_{n_{\boldsymbol{\varepsilon}}})$. The coefficient matrices $\boldsymbol{\Theta}_l$ are the objects of interest: element $\Theta_{i,1,l}$ is defined as the impulse response of variable i to the structural monetary policy shock at horizon l. The SVMA model in Equation (5) encompasses the solution to model (1)-(4) (in principle, all discrete-time dynamic stochastic general equilibrium (DSGE) models) as well as stationary vector autoregressive (VAR) models. In addition, the existence of an instrumental variable (IV), z_t, is assumed that is correlated with the monetary shock $\varepsilon_{1,t}$, but uncorrelated with all others:

$$E(z_t, \varepsilon_{1,t}) \neq 0,\ E(z_t, \varepsilon_{j,\tau}) = 0 \quad \forall (j, \tau) \neq (1, t). \tag{6}$$

Under weak conditions, the SVMA model admits a VAR representation and thus can be estimated with standard reduced-form methods. In particular, the following analysis relies on the estimation of a mixed-frequency Bayesian vector autoregressive (MF-BVAR) model with an instrumental variable approach to identify monetary policy shocks. This specific setup of the time series model delivers a unique combination of well-suited features to recover impulse response functions of fiscal variables to monetary policy shocks, for the following reasons.

First, it requires only minimal assumptions on the data generating process to identify a single structural shock using an instrument. By including z_t as the first endogenous variable in the augmented vector $\tilde{\boldsymbol{y}}_t = (z_t, y_{1,t}, \dots, y_{n,t})'$, the so-called "internal-instrument" approach recommended by Plagborg-Møller and Wolf (2021), the only assumptions for identification are the SVMA model (5) and the IV exclusion restriction (6). In particular, even if the monetary policy shock is noninvertible (i.e., if $\varepsilon_{1,t} \notin \text{span}(\{\tilde{\boldsymbol{y}}_\tau\}_{-\infty<\tau<t})$), impulse response functions $\boldsymbol{\Theta}_l$ can still be consistently estimated. Plagborg-Møller and Wolf (2022) and Forni, Gambetti and Ricco (2022) present evidence that the invertibility assumption for high-frequency monetary policy surprises likely fails, which would invalidate "external-instrument" identification as in Mertens and Ravn (2013).

Second, since the instrument is derived from financial contracts around Federal Open Market Committee (FOMC) announcements and therefore is of high (in principle intra-daily) frequency, the literature uses the highest frequency available to study monetary policy shocks, usually monthly, to mitigate time aggregation bias.[6] Since fiscal variables are only available in quarterly (or even annual) frequency, there is a frequency mismatch. If the true data generating process is of higher frequency than the data used for identification, we generally cannot hope to recover the true structural shocks (Marcellino, 1999). Therefore, the use of a mixed-frequency model is crucial for identification.

Third, a relatively short sample period in combination with a high-dimensional number of endogenous variables warrants the incorporation of prior information to achieve shrinkage, which is implemented here in the form of a Minnesota-type prior. To the classic monetary VAR setup of, e.g., Gertler and Karadi (2015) consisting of an interest rate, production, prices, and a financial conditions measure, at least the two main instruments of fiscal policy have to be added, government spending and taxes. However, since spending and taxes endogenously react to government debt, omitting debt likely leads to misspecification (cf. Mertens and Ravn (2013)). Therefore, including the monetary policy proxy, the minimum number of variables in the VAR is eight. In addition, and unrelated to the dimensionality of the model, Li, Plagborg-Møller and Wolf (2024) recommend the use of a VAR with a shrinkage estimator based on the bias-variance trade-off. Finally, Bayesian posterior inference is exact in finite samples and does not require an explicit theory to accommodate potentially weak instruments.

[6] In this pursuit, Buda et al. (2023) and Jacobson, Matthes and Walker (forthcoming) use daily macroeconomic data. Jacobson, Matthes and Walker (forthcoming) show that even at monthly frequency, time aggregation can bias estimates of monetary policy transmission.

3.2 Data and Model Specification

The baseline VAR model contains the Shadow Rate by Wu and Xia (2016) as a measure of the policy instrument that accounts for the zero lower bound episode, the consumer price index for the aggregate price level, industrial production to capture economic activity at a monthly frequency, and the excess bond premium to account for the effects of monetary policy via financial markets (cf. Gertler and Karadi (2015) and Caldara and Herbst (2019)). In addition, the baseline VAR model includes three key fiscal variables in quarterly frequency: the real (par) value of government debt, real general government spending (both in per capita terms), and the average personal income tax rate. To keep the dimensionality of the VAR manageable, additional variables of interest, such as government transfers, are later added to this baseline model one by one.[7]

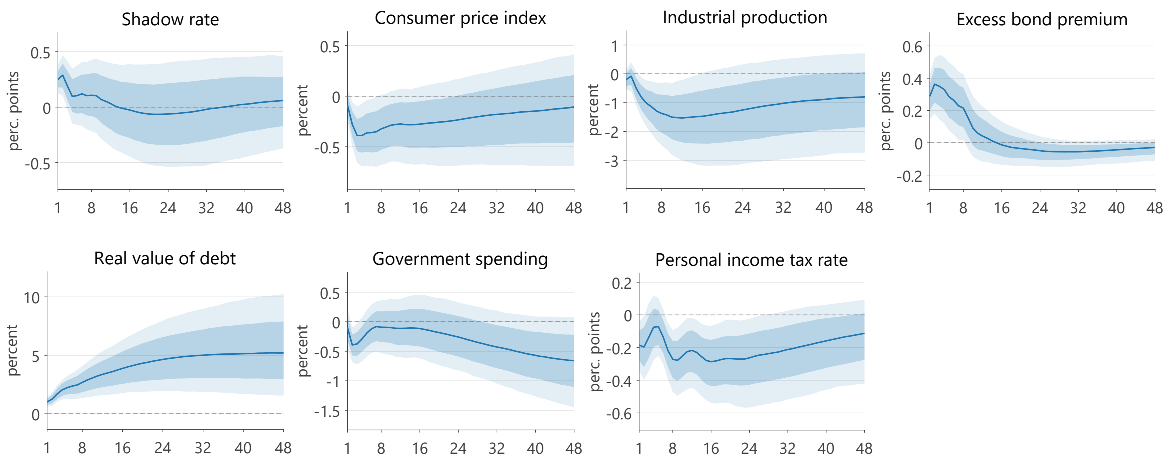
Identification is achieved by use of high-frequency changes in financial market contracts around FOMC monetary policy announcements as an instrument for policy shocks, the current gold standard in the literature, by relying on relatively weak identifying restrictions (e.g., Wolf (2020)). A large literature studies the properties of these surprises and suggested a possible contamination resulting from the Fed's superior information, the so-called "information effect" (cf. Nakamura and Steinsson (2018) and Miranda-Agrippino and Ricco (2021)). Bauer and Swanson (2023*a*) challenge this literature by showing that predictability of surprises is not unique to Fed Greenbook forecasts, instead showing that these surprises are forecastable based on economic and financial news available to the market before FOMC announcements. This undermines the idea of a superior Fed information effect and improves on previous instruments in the literature by additionally controlling for ex-ante predictability (which in turn is rationalized by uncertainty over the Fed reaction function to economic news, what they call the "Fed reacts to news" channel). Therefore, their purged surprises series, developed in Bauer and Swanson (2023*b*), is used to identify the monetary policy shock.

The reduced-form model to be estimated on a sample from April 1988 to December 2019 is the MF-BVAR model of Schorfheide and Song (2015). Because of the high-dimensional problem and relatively short sample size (constrained by the availability of the instrument and the volatility of the Covid-period), a standard Minnesota-type prior is used.[8] The proxy

[7]For a detailed description of the construction of all data series used in the VAR, see Appendix A.1.

[8]The prior is implemented using dummy variables, following Sims and Zha (1998). The hyperparameters λ_1 to λ_5 governing the prior are set as follows: the prior tightness for the autoregressive coefficients of order one, λ_1, and for higher lags λ_2 are set to 5 and 1, respectively, as in Litterman (1986). All remaining hyperparameters, the sum-of-coefficients prior, co-persistence prior of the data, and the weight of the prior on the covariance matrix of the innovations (a diagonal matrix with elements equal to the presample variance of y_t) are all set to 1, in line with Sims and Zha (1998). Furthermore, Jarociński and Karadi (2020) report that these values for the hyperparameters approximately maximize the marginal data density in their very similar application. In addition, as in Born and Pfeifer (2021) and many other studies, I impose the dogmatic prior that the VAR is stable (which it is for most draws anyway). Finally, since the instrument is intended to capture an unpredictable policy innovation, the prior mean on its first autoregressive lag is set to 0 instead of 1.

Figure 1: MF-BVAR: Baseline Responses to a Monetary Policy Shock



Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

by Bauer and Swanson (2023*b*) is added to the VAR and ordered first, which identifies the (relative) structural monetary policy shock by applying a Cholesky decomposition to the covariance matrix of the reduced-form residuals. The MF-BVAR is estimated with 12 lags and a constant. The following figures show point-wise posterior means along with 68% and 90% highest posterior density intervals.[9]

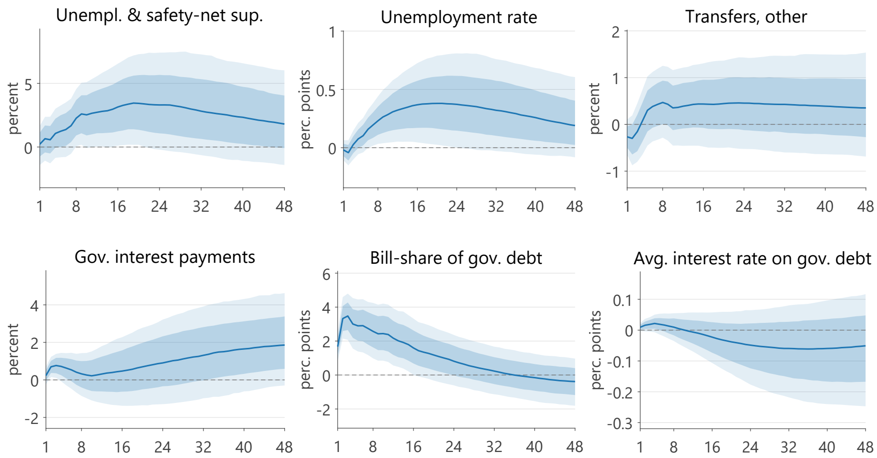
3.3 Baseline Impulse Response Functions to a Monetary Policy Shock

Figure 1 presents the impulse responses to the monetary policy shock for the baseline model. The shock is normalized to a 25 basis point surprise increase in the shadow interest rate. The first row shows the standard reaction of the macroeconomy to a contractionary monetary shock: the short-term nominal interest rate rises, economic activity contracts persistently, prices decline quickly, while financial conditions tighten on impact. These impulse responses are close to Bauer and Swanson (2023*b*) both in shape and magnitude, but also in line with, e.g., Miranda-Agrippino and Ricco (2021), and Jarociński and Karadi (2020).[10] The second row of Figure 1 presents the responses of the fiscal variables. The real value of debt increases strongly and persistently. Real government spending (consumption and investment) does not react much in the short run, but shows a decline after two years. Figure B.1 in the Appendix presents results for government consumption and investment separately, both at the federal

[9] The required number of iterations in all specifications of the MF-BVAR exceeds the minimum number as suggested by the Raftery and Lewis (1992) diagnostic.

[10] Specifically, for the specifications that are closest to the one presented here in terms of variables used, sample, and identification approach, see Bauer and Swanson (2023*b*) Figure 6 right column, Jarociński and Karadi (2020) Figure C.3 in the online appendix, and Miranda-Agrippino and Ricco (2021) Figure 9.

Figure 2: MF-BVAR: Additional Fiscal Responses to a Monetary Policy Shock



Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

and state level, and documents that investment is mainly responsible for the fall in spending. The average tax rate falls, reaching a trough after about 16 months. This tax rate, based on the National Income and Product Account (NIPA) tax base and revenues, is an effective average rate, so it includes variation in tax policy as well as fluctuations due to economic conditions such as a fall in revenue. In summary, Figure 1 suggests that the personal income tax rate falls after a contractionary monetary shock, alongside an increase in the stock of debt and a gradual decline in government spending.[11]

Next to government debt, spending, and taxation, other key government variables are shown in Figure 2. After the contractionary shock, unemployment benefit payments and other safety-net support measures rise moderately to a peak after 18 months. This is in line with a commensurate increase in the unemployment rate. Hence, unemployment and other support benefits increase likely mechanically, and all other transfer payments do not respond. Although there is significant probability mass different from zero in the response of unemployment transfers, the economic magnitude is moderate: Unemployment and other safety-net support measures only average 2.6% of GDP over the sample period. Turning to the interest payments on government debt, in theory, the interest rate increase by the Federal Reserve should increase the debt refinancing conditions of the government. However, in line with a significant outstanding share of long-term debt in the U.S., interest rate payments by the federal government increase only very weakly at first, and with high posterior probability

[11]There is only very weak evidence that the corporate income tax rate reacts, see Figure B.3 in the Appendix. Moreover, corporate income taxation accounts for only about one fifth of the revenue compared to personal income.

only after four years. In fact, this response suggests that the monetary policy shock does not materially increase the average interest rate actually paid on outstanding or newly issued debt, but rather increases total interest payments because the stock of debt increases (see also the discussion of Figures 4 and B.5 below). The response of one such measure, the average interest rate on outstanding government debt in the lower left panel, confirms that there is no lasting increase. Another explanation is given by the share of Treasury-Bills outstanding, i.e., short-maturity debt, that significantly increases. Since long-maturity debt usually carries a higher interest rate, a temporary shift in the composition of debt contributes to low interest payments on debt.

The results in Figure 2 suggest that there is an automatic stabilizer response in cyclical transfers that counteracts the monetary contraction, similarly to the falling tax rate. However, an exogenous increase in the interest rate by the Fed does not lead to large increases in interest expenses on government debt in the short run, and as a result is unlikely to induce large fiscal repercussions via this channel.

3.4 Mechanical Fiscal Adjustments or Policy Action?

The fiscal policy response to the contractionary monetary shock is characterized by a reduction in the average tax rate and by increased transfers in the form of unemployment and safety-net transfers. Are the expansionary fiscal responses a mechanical reaction to economic conditions, i.e., to lower tax income? Or is U.S. fiscal policy systematically reacting by lowering the tax rate? Disentangling tax policy action from non-legislated changes in the tax burden is challenging, since the effective average tax rate may change automatically because of variation in the level of income or changes in stock prices, among other reasons.[12] However, all of these non-policy changes in the tax rate result from a change in the distribution of taxable income, or the tax base. Consequently, a calculation of the average tax rate based on a constant tax base distribution over time reflects changes in the tax schedule only. Such a measure is available in annual frequency by the TAXSIM program of the NBER, covering personal income taxation.[13] Using household data to fix the income distribution of taxpayers in 1984 and correcting the distribution each year by realized inflation, year to year changes in this measure eliminate mechanical variation due to distributional changes and isolate tax policy changes. Importantly, the TAXSIM measure takes into account not only changes in the marginal tax rates, but also changes to tax deductions and tax credit, adding to policy-induced variation in the total tax burden (see Figure A.2 for changes in marginal tax rates for

[12] Inflation is not one of them in this sample, since the U.S. has had automatic annual inflation indexation of federal income tax brackets since 1985.

[13] The TAXSIM microsimulation tax calculator has been used often in the literature on the effects of tax changes on the U.S. economy, see e.g. Barro and Redlick (2011) and Mertens and Montiel Olea (2018). For the TAXSIM program, see Feenberg and Coutts (1993) and `https://www.nber.org/taxsim`.

Figure 3: MF-BVAR (Quarterly-Annual): Response of the Tax Rate of a Fixed Distribution of Taxpayers to a Monetary Policy Shock

Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

different income levels, including the deductions and credits). The tax code and tax burden has undergone large and frequent changes, see Figure A.1 in the Appendix, that also displays other tax rate measures used in the analysis for comparison.

Figure 3 presents the impulse responses to a monetary policy shock in a quarterly-annual model. Compared to Figure 1, there is a clear loss of precision in the estimates resulting from moving to a lower frequency. The consumer price index response is not significant anymore, likely a result of time-aggregation bias. However, qualitatively all results are similar to the baseline monthly-quarterly model. To keep the number of parameters to estimate in check, government debt is retained as the only other fiscal variable, but eight lags are included such that the annual variable may still depend on its own (annual) lag.

The TAXSIM measure, from now on referred to as the policy tax rate, confirms that indeed, the tax rate falls with high posterior probability after about a year and stays persistently lower during the impulse response horizon. Consistent with the average tax rate calculated based on national accounts data in the monthly-quarterly model, the estimates suggest that the fiscal authority reacts by lowering the tax burden with a delay of about a year.[14] Note, however, that the policy tax rate falls by less, therefore automatic income stabilization due to progressive taxation also plays a role. Finally, to assess whether only the average tax burden or also tax progressivity changes, the response of the TAXSIM marginal tax rate is shown in

[14]The impulse response function of the policy tax rate assigns some non-trivial probability mass to the tax change occurring quite quickly, even in the same quarter. Given institutional inertia this is unlikely, and in the robustness analysis below, among other exercises, I impose an institutional constraint that the tax rate cannot change contemporaneously. The results look very similar in magnitude and shape, see Section 3.5.

Figure B.2 in the Appendix. It does not react significantly at any horizon, indicating that policy operates primarily through average rather than marginal rates.

3.5 Robustness Results

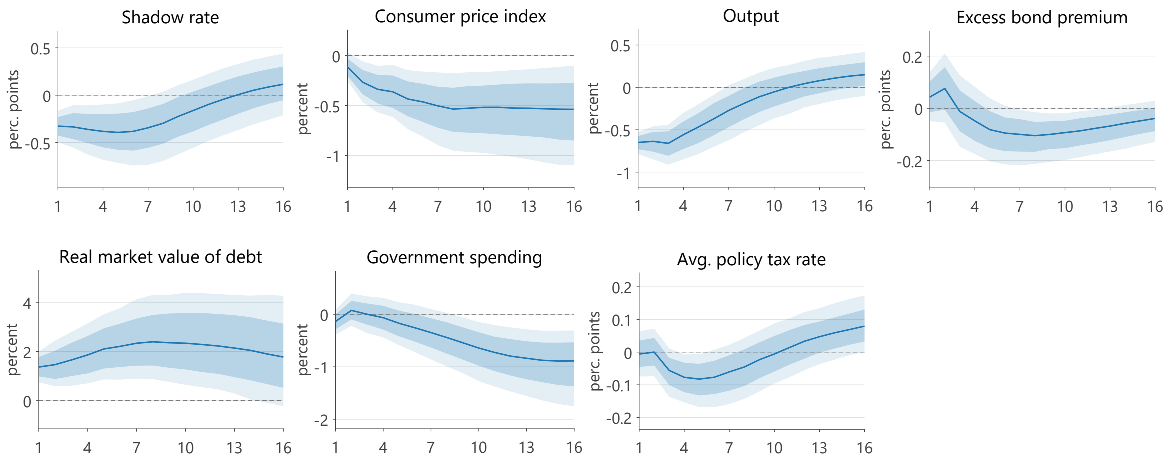
I now present a number of robustness exercises on both the baseline monthly-quarterly VAR as well as the quarterly-annual VAR, with the results relegated to Appendix B.1. Next to changes in the specification of the VARs, I additionally consider an "external-validity" exercise concerning the fiscal responses documented so far, by considering a different but similar source of exogenous variation, an aggregate demand shock. This exercise helps to both alleviate weak-instrument concerns of monetary shocks in driving variation in fiscal instruments and to interpret the observed fiscal reaction.

Figure B.6 panels a) and b) show that the results are robust to using the 1-year Treasury yield instead of the Shadow Rate, and to using tax revenues instead of the tax rate. A concern in the fiscal response could be that it might differ depending on which political party is in power (i.e., to which party the President belongs), or which has a majority in the Senate. If that were the case, including a dummy for a political party in power should materially alter the estimated parameters and therefore the impulse responses. Figures B.6 panels c) and d) show that the results are hardly changed in that case. Finally, the results are robust to excluding the Zero Lower Bound (ZLB) period, see panel e).

For the quarterly-annual VAR and the evidence regarding the active policy-induced changes in the tax burden, the following robustness checks have been investigated: first, the implicit assumption in unrestricted VAR models that endogenous variables can adjust contemporaneously has often been questioned in the fiscal policy literature — the belief that fiscal policy cannot adjust quickly famously has been used for identification (Blanchard and Perotti, 2002). This simplification implicit in general VAR models can be addressed in two ways. First, an institutional constraint can be directly imposed by a zero restriction that the monetary shock does not move the tax rate contemporaneously. Second, instead of relying on the mixed-frequency inference of missing values, it can be imposed on the data that the tax rate is constant during a calendar year by converting the tax rate to quarterly frequency by repeating values. Although both assumptions are more restrictive than actual U.S. legislation practice, the results are very similar and reported in Figures B.8 and B.9 in the Appendix.[15] For both robustness checks, the overall magnitude and the trough response after roughly five quarters align well with the baseline Figure 3. Another robustness check on whether taxes are actively adjusted can be conducted by using another measure of changes in tax rates, namely cyclically adjusted federal tax revenues by the Congressional Budget Office (CBO).

[15] Romer and Romer (2010) analyze post-WWII tax changes until 2007 and document that tax changes occurred in any given quarter.

Figure 4: MF-BVAR (Quarterly-Annual): Baseline Responses to the "Main Business-Cycle Shock" by Angeletos, Collard and Dellas (2020)



Notes: Impulse response functions to the Main Business-Cycle shock, scaled to match the same trough response in output as to a monetary policy shock (see Figure 5). Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

By purging federal tax revenues from fluctuations due to economic conditions, in principle, this measure should show no decline if statutory tax rates (and deductions and credits) stay unchanged. However, in Appendix B.1, Figure B.7 it is shown that this measure falls as well, albeit less significantly.

The robustness results reported so far aim at establishing confidence in the estimation of the fiscal reaction after a monetary shock. Since these impulse responses are going to be the key empirical moments to discipline the HANK model estimation and the identification of the fiscal rule parameters, one might, however, worry about weak instrument concerns since monetary policy shocks are usually found to only account for a small share of business-cycle variation (e.g., Caldara and Herbst (2019), Plagborg-Møller and Wolf (2022)). To alleviate this concern, I estimate impulse responses of fiscal variables to a shock that is by construction responsible for a large share of business-cycle variation, the "Main Business-Cycle shock" (MBC) shock by Angeletos, Collard and Dellas (2020).[16] This serves two purposes: first, it provides an additional set of arguably strong identifying variation for the estimation of the fiscal rule parameters of the micro-founded model in Section 4. Second, it provides an external robustness check on the fiscal response to monetary policy: since the MBC shock is an aggregate demand disturbance, it sheds light on the generality of the fiscal response.

Figure 4 shows the results for the MBC shock estimated in the quarterly-annual MF-

[16] Angeletos, Collard and Dellas (2020) argue that the MBC shock accounts for the largest share of variation by a single source (the unemployment rate) in typical U.S. macroeconomic time series by construction.

BVAR, estimated over the post-Volcker disinflation sample, consistent with the empirical analysis so far and the calibration and estimation of the microfounded model in Section 4.[17] Instead of the real value of debt outstanding and industrial production, Figure 4 shows the responses of output and the real market value of debt, since these variables have a direct counterpart in the micro-founded model in Section 6.[18] In general, the fiscal response to this aggregate demand shock is remarkably similar to the monetary disturbance: debt increases, government spending falls with a substantial delay, and the tax rate declines after about a year. Figure B.5 in the Appendix shows that transfers and government interest payments respond very similarly as well, even though the shadow rate is declining instead of increasing, compared to the monetary shock. All of the responses have narrower credible bands than the corresponding monetary policy impulse responses, underlining that they provide stronger moment conditions for estimation.

3.6 Discussion of Empirical Results

In summary, a monetary policy shock induces debt-financed countercyclical tax and transfer policy. Government spending falls as the debt level rises, while automatic transfers in the form of unemployment and safety-net payments are triggered by a higher unemployment rate. This fiscal policy response obtains not only for a monetary policy shock, but also for a more general aggregate demand shock. Three conclusions can be drawn at this point.

First, these results suggest that systematic fiscal policy counteracts the monetary shock, both due to automatic stabilizers in the form of transfers and progressive taxation, as well as an active reduction in the tax burden. That fiscal policy may at times be countercyclical has been documented repeatedly in the literature, e.g., Blanchard (2025) finds both automatic as well as discretionary countercyclical elements. Indeed, a business-cycle stabilization motive of tax policy has been documented in the statements of tax legislation itself (Romer and Romer, 2010). However, the evidence presented above shows that fiscal policy is countercyclical even conditional on a monetary policy shock. This result therefore reveals an analogy to the literature on fiscal stimulus effects, where it is well understood that monetary policy, if it operates an active Taylor rule, raises interest rates in response to expansionary fiscal policy. Fiscal multipliers thus depend on the systematic monetary policy response (see, e.g., Christiano, Eichenbaum and Rebelo (2011), Woodford (2011), Cloyne, Jordà and Taylor (2023), Hack, Istrefi and Meier (2023)). The results suggest the same conclusion for the effects of monetary policy.

Second, the muted response of interest payments on government debt suggests that the temporarily higher Federal Funds rate does not lead to materially higher interest payments for

[17] Bernanke and Mihov (1998) identify February 1984 as the start of the post-Volcker disinflation regime, consequently the sample runs from 1984Q1 to 2017Q4, until which the MBC shock is available.

[18] The responses of industrial production and the par value of debt are very similar.

the government, due to a change in the composition to more short-term debt, which results in a roughly constant average interest rate on outstanding government debt. Instead, the increase in government debt likely results from the shortfalls in tax revenues, the decline in the price level, as well as the increased transfer payments.

Third, fiscal consolidation efforts of the higher government debt level seem to fall heavily on reduced government spending. Taxes and transfers are both initially contributing to the rise in debt, not reducing it.

What we can learn about a fiscal channel of monetary policy only from empirical impulse responses is limited, however. All of the fiscal adjustments coincide not only with the higher interest rate by the Fed, but with a falling price level, falling output, and tighter financial conditions. Whether the fiscal authority reacts to interest rates *per se*, or only to output and/or inflation is a priori unclear, as is the contribution and pace of debt consolidation from the different fiscal instruments. To learn about the motives behind the fiscal adjustments, the policy rules governing the fiscal actions need to be estimated themselves. Then, the estimated model can be used to conduct counterfactual experiments to quantify the contributions of the fiscal responses to monetary policy transmission.

4 A Two-Asset Heterogeneous Agent New Keynesian Model

The previous section provided a detailed description of the average responses of fiscal policy variables in the wake of a monetary shock. To learn about the role of these fiscal adjustments in monetary transmission and about the characterization of systematic fiscal policy rules, this section presents a state-of-the-art theoretical business-cycle model that can match the empirical estimates. Key ingredients necessary are therefore a rich description of the transmission of monetary and fiscal policy, especially tax policy. Heterogeneous Agent New Keynesian (HANK) models meet these requirements and allow explicitly to study how tax policy affects monetary transmission in the presence of progressive taxation. The HANK model described here hence features progressive taxation and, in line with the data, a fiscal authority that sets the statutory tax rate. The model follows otherwise Bayer, Born and Luetticke (2023, 2024) and features household heterogeneity that matches the income and wealth distribution in the data, as well as nominal and real rigidities commonly used to match the aggregate effects and persistence of monetary policy, as documented in the previous section.

4.1 Households

There is a continuum of ex-ante identical households of measure 1, indexed by i. They are infinitely lived, have time-separable preferences in consumption and labor, and discount time by the subjective discount factor β. There are two types of households, workers and entrepreneurs. Workers supply their labor to unions, whereas entrepreneurs do not work but earn firm profits. All households rent out physical capital and decide on their consumption and saving choices by optimizing intertemporally, subject to a budget constraint. In addition, they insure against idiosyncratic risk by optimally adjusting a portfolio of liquid bonds and less liquid capital. Hence they finance consumption c_{it} by deriving income from potentially supplying labor n_{it}, renting out capital k_{it}, earning interest on their bond holdings b_{it}, and potentially collecting profits of firms Π_t^F, and from unions, Π_t^U. Their labor and profit incomes are subject to a progressive income tax as in Heathcote, Storesletten and Violante (2017), who show that their functional form fits US income tax data well. It is characterized by a level parameter τ_t^l and a progressivity parameter τ^p.

More in detail, households have Greenwood, Hercowitz and Huffman (1988) (GHH) preferences with the functional form

$$u(x_{it}) = \frac{1}{1-\xi}\left(c_{it} - h_{it}^{1-\tau^p}\frac{n_{it}^{1+\gamma}}{1+\gamma}\right)^{1-\xi}, \tag{7}$$

where x_{it} is the composite demand of household i for goods consumption c_{it} and leisure $(1-n_{it})$.[19] ξ denotes the constant relative risk aversion parameter and γ the inverse of the Frisch elasticity of labor supply. The choice of GHH utility and the specific functional form simplifies the analysis since all households supply $n_{it} = N(w_t)$ hours of labor, which is in line with the business-cycle literature finding small wealth effects in labor supply (see, e.g., Schmitt-Grohé and Uribe (2012) and Born and Pfeifer (2014)). It is assumed that idiosyncratic labor productivity h_{it} evolves according to a log $-$AR(1) process, but additionally there is a fixed probability ν to transition to an entrepreneur state. Entrepreneurs do not work but instead receive the pure rents from monopolistic competition in the goods sector and capital creation. With probability ι, an entrepreneur returns to the worker state with average productivity, which is normalized to 1. The inclusion of the entrepreneur state, going back to Castaneda, Dıaz-Giménez and Rıos-Rull (1998), helps to match the income and wealth distribution, but also solves the challenge of allocating pure rents in the economy without distorting factor prices or introducing a tradeable claim to the profit shares. The idiosyncratic productivity

[19] This functional form, without loss of generality, simplifies the household problem, as idiosyncratic productivity h_{it} drops out from the first-order condition. Goods consumption of household i in period t is the usual Dixit-Stiglitz aggregator over j differentiated goods:

$$c_{it} = \left(\int c_{ijt}^{\frac{\eta-1}{\eta}} dj\right)^{\frac{\eta}{\eta-1}}, \tag{8}$$

with associated price p_{jt} such that the aggregate price level is $P_t = (\int p_{jt}^{1-\eta} dj)^{\frac{1}{1-\eta}}$. Then, the demand for each of the varieties is given by

$$c_{ijt} = \left(\frac{p_{jt}}{P_t}\right)^{-\eta} c_{it}. \tag{9}$$

process is therefore described as

$$h_{it} = \begin{cases} \exp(\rho_h \log h_{it-1} + \epsilon^h_{it}) & \text{with probability } 1-\nu \text{ if } h_{it-1} \neq 0, \\ 1 & \text{with probability } \iota \text{ if } h_{it-1} = 0, \\ 0 & \text{otherwise.} \end{cases} \tag{10}$$

Given their net labor income after progressive income taxation (see Equation (12) below), households optimize saving and portfolio choices intertemporally. To insure against idiosyncratic uncertainty, households hold liquid bonds and illiquid capital. The liquid government bond pays the nominal gross interest rate R^b_t, which is set one period before by the central bank. Access to the capital market is limited due to a random participation constraint. With probability λ, households can adjust their holdings of capital (thus the same fraction of households each period are 'adjusters'), leading to a tradeoff between the higher yield of capital and smoother consumption due to the liquidity of bonds. Finally, taking all the above income components together, the household's budget constraint reads:

$$\begin{aligned} c_{it} + b_{it+1} + q_t k_{it+1} = b_{it}\frac{A_t R^b_t}{\pi_t} &+ (q_t + r^k_t)k_{it} + y_{it}, \\ b_{it+1} &\geq 0, \\ k_{it+1} &\geq 0, \end{aligned} \tag{11}$$

where q_t is the price of capital and r^k_t its dividend net of depreciation, $\pi_t = \frac{P_t}{P_{t-1}}$ realized inflation, and A_t is included as a stand-in for a typical demand shock in the spirit of a risk-premium or discount-factor shock and evolves according to a $\log - \mathrm{AR}(1)$ process with persistence ρ_A.[20] y_{it} is net income after progressive income taxation:

$$y_{it} = \mathcal{I}_{h_{it}\neq 0}\left[(1-\tau^l_t)\big(w_t h_{it} N_t\big)^{1-\tau^p} + (1-\tau_t)\frac{\Pi^U_t}{\mu^W}\right] + \mathcal{I}_{h_{it}=0}\,(1-\tau^l_t)\left(\frac{\Pi^F_t}{\mu^E}\right)^{1-\tau^p}, \tag{12}$$

where τ^l_t is the level parameter of the tax code, $\tau^p \geq 0$ governs tax progressivity, τ_t is the effective average tax rate, and μ^W and μ^E are the stationary masses of workers and entrepreneurs. Π^U_t and Π^F_t denote aggregate union and firm profits, so that each worker receives Π^U_t/μ^W and each entrepreneur Π^F_t/μ^E. When $\tau^p = 0$, Equation (12) collapses to a flat tax at rate τ^l_t. Union profits are taxed at the effective average rate since they accrue proportionally across workers regardless of productivity. The household's optimization problem can now be stated as follows. Let $\Theta_t(b, k, h)$ be the distribution of households over the

[20] Since $\bar{A} = 1$ and the model is solved by first-order perturbation, the wedge between the household bond return and the government's debt service vanishes.

idiosyncratic states in t. Agents face aggregate risk, therefore the aggregate states $\Theta_t(b,k,h)$ and R_t matter for the household problem through prices. To simplify notation, instead of explicitly writing the household problem as a function of aggregates states, value functions are treated as time-dependent. Furthermore, letting $'$ denote the next period values and dropping the indexes to the idiosyncratic states, the household's dynamic programming problem is then summarized by the following Bellman equations:

$$\begin{aligned} V_t^a(b,k,h) &= \max_{b'_a,k'}\{u(x(b,b'_a,k,k',h)) + \beta\mathbb{E}_t\mathbb{W}_{t+1}(b'_a,k',h')\}, \\ V_t^n(b,k,h) &= \max_{b'_n}\{u(x(b,b'_n,k,k,h)) + \beta\mathbb{E}_t\mathbb{W}_{t+1}(b'_n,k,h')\}, \\ \mathbb{W}_{t+1}(b',k',h') &= \lambda V_{t+1}^a(b',k',h') + (1-\lambda)V_{t+1}^n(b',k',h'). \end{aligned} \tag{13}$$

Maximization is subject to (11), and the expectation is taken with respect to all stochastic processes, conditional on the period t states. A value function or optimal policy function with an a refers to the adjustment case ($k' \neq k$) and an n to non-adjustment ($k' = k$). The law of motion for the distribution (density) of households over the idiosyncratic states evolves according to

$$\begin{aligned} \Theta_{t+1}(b',k',h') = \lambda &\int_{b'=b^*_{a,t}(b,k,h),k'=k^*_t(b,k,h)} \Phi(h,h')d\Theta_t(b,k,h) \\ &+ (1-\lambda)\int_{b'=b^*_{n,t}(b,k,h),k'=k} \Phi(h,h')d\Theta_t(b,k,h) \end{aligned} \tag{14}$$

In words, Equation (14) describes how the current measure Θ_t over (b,k,h) translates into a measure tomorrow, by summarizing how individuals move within the distribution. The transition of assets is given by the policy rules $(b^*_{a,t}, b^*_{n,t}, k^*_t)$ and $\Phi(\cdot)$ is a Markov transition matrix approximating the stochastic process (10), obtained using Tauchen's method (Tauchen, 1986).

4.2 Firms

The firm sector comprises four sub-sectors: (a) unions and labor packers in the labor sector, (b) intermediate goods producers, (c) final goods producers, and (d) capital goods producers, whose structures and interactions are laid out in the following. Profit-maximization decisions in the firm sector, involving intertemporal choices like price and wage setting, are delegated to a mass-zero group of risk-neutral households (managers) compensated by a share in profits for tractability and without consequence for first-order perturbation solutions of the model. These managers do not participate in asset markets, and their consumption doesn't affect resource constraints, therefore the firm side remains standard compared to representative agent New Keynesian models.[21]

4.2.1 Unions and Labor Packers

There exists a unit mass of unions indexed by j, who buy labor services from households (n_{it}) and transform them into labor variety $\hat{n}_{jt}$. The labor varieties are sold to perfectly competitive labor packers, which in turn bundle the varieties to a final labor service

$$N_t = \left(\int \hat{n}_{jt}^{\frac{\zeta-1}{\zeta}} dj \right)^{\frac{\zeta}{\zeta-1}}, \tag{15}$$

that is supplied to intermediate goods producers. Labor packers minimize costs such that each union j faces a demand curve

$$\hat{n}_{jt} = \left(\frac{W_{jt}}{W_t^F} \right)^{-\zeta} N_t. \tag{16}$$

Since unions have market power, they can set the nominal wage W_{jt} at which they sell labor variety j to labor packers, who charge W_t^F to firms. Paying households the nominal wage $W_t < W_{jt}$, unions thus maximize expected discounted real profits, subject to a Calvo (1983)-adjustment friction:

$$\max_{W_{jt}} E_0 \sum_{t=0}^{\infty} \beta^t \lambda_w^t \frac{W_t^F}{P_t} \left\{ \left(\frac{W_{jt}}{W_t^F} - \frac{W_t}{W_t^F} \right) \left(\frac{W_{jt}}{W_t^F} \right)^{-\zeta} N_t \right\}, \tag{17}$$

where λ_w is the probability of having to keep wages constant. Given that all unions are symmetric, linearization around the stationary, symmetric equilibrium gives rise to a wage Phillips curve (ignoring higher-order terms):

$$\log \left(\frac{\pi_t^W}{\bar{\pi}^W} \right) = \beta \mathbb{E}_t \log \left(\frac{\pi_{t+1}^W}{\bar{\pi}^W} \right) + \kappa_w \left(\frac{w_t}{w_t^F} - \frac{\zeta - 1}{\zeta} \right), \tag{18}$$

where $\pi_t^W = \frac{W_t^F}{W_{t-1}^F} = \frac{w_t^F}{w_{t-1}^F} \pi_t$ is wage inflation, $\frac{\zeta}{\zeta-1}$ denotes the target mark-down of wages the union pays to households, W_t, relative to what is paid by firms, W_t^F, and $\kappa_w = \frac{(1-\lambda_w)(1-\lambda_w \beta)}{\lambda_w}$.

[21]Due to incomplete asset markets, managers do not have access to the usual Arrow-Debreu stochastic discount factor in the standard profit maximization problems, hence, the simplifying assumption of no asset market participation. Therefore, they discount via the subjective discount factor β.

4.2.2 Intermediate Goods Producers

Perfectly competitive intermediate goods producers operate the constant returns to scale production function

$$Y_t = N_t^{\alpha}(u_t K_t)^{(1-\alpha)}, \tag{19}$$

featuring variable capital utilization u_t, to produce the homogeneous output good Y_t.[22] They charge mc_t to the final goods producers, hence the standard firm profit maximization problem reads $\max\limits_{\{K,N,u\}} mc_t Y_t - w_t^F N_t - [r_t^k + q_t \delta(u_t)]K_t$ and yields the real wage and user cost of capital, given by the marginal products of labor and effective capital, as well as the optimality condition for capital utilization:

$$w_t^F = \alpha mc_t \left(\frac{u_t K_t}{N_t}\right)^{1-\alpha}, \tag{20}$$

$$r_t^k + q_t \delta(u_t) = u_t(1-\alpha)mc_t \left(\frac{N_t}{u_t K_t}\right)^{\alpha}, \tag{21}$$

$$q_t \left[\delta_1 + \delta_2(u_t - 1)\right] = (1-\alpha)mc_t \left(\frac{N_t}{u_t K_t}\right)^{\alpha}, \tag{22}$$

where q_t is the price of capital goods.

4.2.3 Final Goods Producers

A unit mass of final good producers differentiate the homogeneous intermediate good Y_t and set prices. Analogous to unions, they face Calvo (1983)-adjustment frictions and a demand function $y_{jt} = \left(\frac{p_{jt}}{P_t}\right)^{-\eta} Y_t$ for all j. Firm's managers maximize future expected discounted real profits:

$$\max_{p_{jt}} E_0 \sum_{t=0}^{\infty} \beta^t \lambda_Y^t (1-\tau_t) \left\{ \left(\frac{p_{jt}}{P_t} - \frac{MC_t}{P_t}\right) \left(\frac{p_{jt}}{P_t}\right)^{-\eta} Y_t \right\}, \tag{23}$$

where λ_Y is the probability that prices stay constant. As for unions, a first-order approximation and focusing on a symmetric equilibrium gives rise to a price Phillips curve:

$$\log\left(\frac{\pi_t}{\bar{\pi}}\right) = \beta \mathbb{E}_t \log\left(\frac{\pi_{t+1}}{\bar{\pi}}\right) + \kappa_Y \left(mc_t - \frac{\eta - 1}{\eta}\right). \tag{24}$$

π_t is the gross inflation rate with steady state $\bar{\pi}$, mc_t are real marginal costs, $\frac{\eta}{\eta-1}$ is the target markup, and $\kappa_Y = \frac{(1-\lambda_Y)(1-\lambda_Y \beta)}{\lambda_Y}$.

[22] A higher utilization of capital increases depreciation according to the function $\delta(u_t) = \delta_0 + \delta_1(u_t - 1) + \delta_2/2(u_t - 1)^2$. Assuming $\delta_1, \delta_2 > 0$, the function is (locally) increasing and convex, and without loss of generality, steady state utilization is normalized to 1.

4.2.4 Capital Goods Producers

Finally, capital goods producers turn the final good into capital goods, by maximizing the expected discounted value of future profits, given the cost of capital goods q_t:

$$E_0 \sum_{t=0}^{\infty} \beta^t I_t \left\{ q_t \left[1 - \frac{\phi}{2} \left(\log \frac{I_t}{I_{t-1}} \right)^2 \right] - 1 \right\}. \tag{25}$$

The optimality condition is given by

$$q_t \left[1 - \phi \log \frac{I_t}{I_{t-1}} \right] = 1 - \beta \mathbb{E}_t \left[q_{t+1} \phi \log \frac{I_{t+1}}{I_t} \right], \tag{26}$$

where all terms irrelevant for first-order solutions have been dropped. The functional form makes sure that in steady state, the adjustment costs are zero. Then, since all capital goods producers are symmetric, the aggregate law of motion for capital can be written as

$$K_t - (1 - \delta(u_t))K_{t-1} = \left[1 - \frac{\phi}{2} \left(\log \frac{I_t}{I_{t-1}} \right)^2 \right] I_t. \tag{27}$$

4.3 Monetary and Fiscal Policy Description

The government sector operates fiscal and monetary authorities, with the latter controlling the nominal interest rate according to a Taylor (1993)-type rule. The identified shocks in Section 3 correspond to the i.i.d. shock term ε_t^R, while the Taylor rule exhibits endogenous persistence via interest rate smoothing:

$$\frac{R^b_{t+1}}{\bar{R}^b} = \left(\frac{R^b_t}{\bar{R}^b} \right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}} \right)^{(1-\rho_R)\theta_\pi} \left(\frac{Y_t}{Y_{t-1}} \right)^{(1-\rho_R)\theta_Y} \varepsilon_t^R. \tag{28}$$

As in Bayer, Born and Luetticke (2024), the effective average tax rate τ_t is

$$1 - \tau_t = (1 - \tau_t^l) \frac{\mathbb{E}\left[\left(w_t h_i N_t + \mathcal{I}_{h_i=0} \Pi_t^F \right)^{1-\tau^p} \right]}{\mathbb{E}\left[w_t h_i N_t + \mathcal{I}_{h_i=0} \Pi_t^F \right]}, \tag{29a}$$

$$1 - \tilde{\tau}_t = (1 - \tau_t^l) \frac{\mathbb{E}\left[\left(\bar{w}\, h_i\, \bar{N} + \mathcal{I}_{h_i=0} \bar{\Pi}^F \right)^{1-\tau^p} \right]}{\mathbb{E}\left[\bar{w}\, h_i\, \bar{N} + \mathcal{I}_{h_i=0} \bar{\Pi}^F \right]} = (1 - \tau_t^l)\, \bar{\mathrm{G}}\mathrm{I}, \tag{29b}$$

where $\mathbb{E}[\cdot]$ denotes the cross-sectional expectation over the (invariant) h-marginal Θ^h of the joint distribution. Equation (29a) defines the *effective* average tax rate τ_t, which responds to current income levels through the progressive tax schedule. For that reason, it is outside of the immediate control of the government. Equation (29b) defines the *statutory* average tax rate $\tilde{\tau}_t$, which evaluates the same tax code at steady-state incomes. When gross income

$\bar{\text{GI}}$ is constant, $\tilde{\tau}_t$ moves one-for-one with τ_t^l and reflects changes to policy only, in line with the empirical evidence on the average policy tax rate. In contrast, the effective rate τ_t additionally responds to income changes away from steady state, providing an automatic stabilization channel through the progressive tax code. The fiscal rules for the governments policy decisions $\{\tilde{\tau}_t, G_T\}$ are otherwise non-linear versions of equations (3) and (4), each additionally including an autoregressive lag component:

$$\frac{\tilde{\tau}_t}{\bar{\tau}} = \left(\frac{\tilde{\tau}_{t-1}}{\bar{\tau}}\right)^{\rho_\tau} \left(\frac{Y_t}{\bar{Y}}\right)^{(1-\rho_\tau)\gamma_Y^\tau} \left(\frac{B_t}{\bar{B}}\right)^{(1-\rho_\tau)\gamma_B^\tau} \tag{30}$$

$$\frac{G_t}{\bar{G}} = \left(\frac{G_{t-1}}{\bar{G}}\right)^{\rho_G} \left(\frac{Y_t}{\bar{Y}}\right)^{(1-\rho_G)\gamma_Y^G} \left(\frac{B_t}{\bar{B}}\right)^{-(1-\rho_G)\gamma_B^G} \tag{31}$$

$$G_t = B_{t+1} + T_t - R_t^b/\pi_t \, B_t, \tag{32}$$

where total tax revenues are $T_t = \tau_t \left(w_t N_t + \Pi_t^U + \Pi_t^F\right)$. Spending and taxes are assumed to respond to economic conditions and debt. The rules are kept deliberately standard and flexible, and Equation (32) residually determines debt via the government budget constraint. Appendix C.2 details an extension where the government issues long-term debt instead of short-term debt. Furthermore, in another extension, government spending and taxes are allowed to respond to inflation and the nominal interest rate directly, with the results presented in Section D.2.

4.4 Market Clearing, Equilibrium, and Solution

Bond market clearing requires the aggregate supply of government bonds to equal household demand:

$$B_{t+1} = \int \lambda b_{a,t}^*(b,k,h) + (1-\lambda) b_{n,t}^*(b,k,h) d\Theta_t(b,k,h), \tag{33}$$

where, again, the dependence of the optimal policy functions b^* on t summarizes that they are a function of the continuation value $\mathbb{W}_{t+1}$ and prices $(R_t^b, r_t^k, q_t, \Pi_t^F, \Pi_t^U, w_t, \pi_t)$. Similarly for the capital market, the aggregate supply of capital rented out by households has to equal capital demand from firms

$$K_{t+1} = \int \lambda k_t^*(b,k,h) + (1-\lambda) k d\Theta_t(b,k,h), \tag{34}$$

where $(1-\lambda)k$ is the fraction of capital not traded. The labor market clears at the competitive wage given in Equation (20). Then, the goods market clears due to Walras' law. The definition of the sequential competitive equilibrium, as well as the solution method for its computation are relegated to Appendix C.1.

5 Model Calibration and Estimation

The model is estimated using a two-step approach, in line with much of the impulse response matching literature. First, parameters determining the steady state are calibrated. Second, a limited information Bayesian version of Christiano, Eichenbaum and Evans (2005) is used to estimate parameters that determine the model's dynamics. The main focus lies on the estimation of the model utilizing the monetary policy impulse responses, but Section 6 presents results for the estimation on the MBC shock impulse responses as well.

5.1 First Step: Calibration

The calibration of the steady state aims at aligning the model's distribution of households along the income and wealth distribution with the data. This is key to match the cross-sectional distribution of MPCs in the data, which determines to a large extent the effects of changes in aggregate demand. To be consistent with the empirical analysis, the model is calibrated to the post-Volcker disinflation period of the U.S. economy. Bernanke and Mihov (1998) identify February 1984 as the end of the Volcker disinflation, therefore the calibration sample is $1984 - 2019$. Table 1 summarizes the parameters of the model that are calculated either directly from long-run time series averages to represent steady state ratios, or internally calibrated to match such targets. The moments are: (i) the average ratio of illiquid assets/capital to (annual) output, $\frac{K}{Y} = 2.83$, (ii) the liquid to illiquid assets ratio, $\frac{B}{K} = 0.09$, and (iii) the top 10% wealth share of 68%. All calibrated parameters are determined jointly. The preference parameters ξ and γ are set to standard values in the literature, and the persistence and variance of the autoregressive idiosyncratic productivity process to the values found in Storesletten, Telmer and Yaron (2004). ι gives the transition probability from entrepreneur to worker, which is matched with the probability to fall out of the top 1% of the income distribution of the U.S. in a given year according to the estimates in Guvenen, Kaplan and Song (2014). The portfolio adjustment probability is set to match the average liquidity (privately and domestically held government bonds), and the probability to transition from a worker to an entrepreneur is calibrated to match the upper end of the wealth distribution. The parameters of the firms are set to standard values in the literature. Tax progressivity is calculated using average and average marginal tax rates, as in Ferriere and Navarro (2025).

Table 1: Calibrated Parameters in the HANK Model

Parameter	Value	Description	Target or source
Households			
ξ	2.0	Relative risk aversion	Standard value
β	0.975	Subjective discount factor	$K/Y = 2.83$
γ	2.0	Inverse of Frisch elasticity	Chetty et al. (2011)
λ	6.20%	Portfolio adjustment probability	$B/K = 0.09$
ρ_h	0.98	Persistence labor income	Storesletten, Telmer and Yaron (2004)
σ_h	0.12	Labor income stand. dev.	Storesletten, Telmer and Yaron (2004)
ι	6.25%	Transition prob. from E. to W.	Guvenen, Kaplan and Song (2014)
ν	0.062%	Transition prob. from W. to E.	Top 10% wealth share = 0.68
Firms			
α	0.61	Share of labor	Penn World Table 10.01
δ_0	1.5%	Depreciation rate	6.2% p.a.
$\bar{\eta}$	8	Elasticity of substitution	Price markup 15%
$\bar{\zeta}$	8	Elasticity of substitution	Wage markup 15%
Government			
$\bar{\tau}$	0.15	Steady-state avg. tax rate	$G/Y = 19\%$
τ^p	0.10	Tax progressivity	See Appendix A.2
$\bar{R}_b$	1.00	(Gross) nominal rate	Real MZM own rate ≈ 0
$\bar{\pi}$	1.00	(Gross) inflation	

Notes: The model is calibrated in quarterly frequency. For the data sources and definitions, see Appendix A.2. Note that the RANK economy requires a recalibration, see Appendix D.1.

5.2 Second Step: Estimation

The IRF matching procedure (and exposition) follows Christiano, Trabandt and Walentin (2011). $\boldsymbol{y}_t$ contains the variables in the VAR (of dimension $n \times 1$) and $\hat{\boldsymbol{\psi}}$ collects the empirical IRFs of horizon h, stacked, such that $\hat{\boldsymbol{\psi}}$ has dimension $(n^*h \times 1)$. The estimation strategy is to treat $\hat{\boldsymbol{\psi}}$ as "data" and finding an estimator $\boldsymbol{\theta}^*$ that minimizes the distance to the model impulse responses $\boldsymbol{\psi}(\boldsymbol{\theta})$. $\hat{\boldsymbol{\psi}}$ contains the impulse responses of the annualized nominal interest rate, output, the real market value of debt (to match the models one-period debt), real government spending, and the average policy tax rate (corresponding to the model's statutory average tax rate, $\tilde{\tau}_t$).[23] Since industrial production only represents a small fraction of total production, it is replaced by a measure of (detrended) output, the output gap as calculated by the CBO, which is more in line with the output concept in the model, Y_t. The

[23]In general, $\bar{\tau} \neq \bar{\tau}_{\text{empirical}}$, since federal personal income tax revenues do not constitute the only source of revenue for the U.S. government (unlike in the model), distorting percentage point calculations. To ensure that the model reproduces the correct magnitudes as in the data, $\hat{\boldsymbol{\psi}}$ contains the empirical tax rate response transformed to percent deviations from steady state, by demeaning and dividing by the sample mean.

parameter vector is thus given by[24]

$$\boldsymbol{\theta} = (\delta_2, \phi, \kappa_Y, \kappa_w, \rho_R, \sigma_R, \theta_\pi, \theta_Y, \rho_G, \gamma_B^G, \gamma_Y^G, \rho_\tau, \gamma_B^\tau, \gamma_Y^\tau)'. \tag{35}$$

The asymptotic variance of the normally distributed $\hat{\boldsymbol{\psi}}$, $\boldsymbol{V}(\boldsymbol{\theta}_0, T)$, is assumed to be diagonal and known, as is common in the literature (e.g., Bayer, Born and Luetticke (2023)). It contains on the diagonal the squared standard error of the empirical impulse response to all n variables, at all horizons. Since the MF-BVAR model is in monthly frequency (except for the average policy tax rate) but the DSGE model in quarterly frequency, the empirical impulse responses are averaged to quarterly, as in Jarociński and Karadi (2020). The standard errors are computed using the posterior distributions of the averaged impulse responses.

Columns $1-4$ of Table 2 present the prior distributions, means, and variances of the estimated parameters. In general, the prior probability density functions and values are standard in the literature (Smets and Wouters (2007), Justiniano, Primiceri and Tambalotti (2011), Bayer, Born and Luetticke (2023)). A Gamma distribution with prior mean 5 is imposed for $\delta_s = \delta_2/\delta_1$, the elasticity of marginal depreciation with respect to capital utilization, and a prior mean of 4 for the parameter ϕ, controlling investment adjustment costs. The prior for the slope of the New Keynesian price Phillips curve is informed by Nakamura and Steinsson (2008), who report a frequency of price changes in quarterly terms of 33% (or an average duration of prices of 3 quarters), implying $\kappa = 0.18$. In line with the view in the literature that wages are more sticky than prices, the prior mean for κ_w is set such that wages reset on average every 6 quarters (Auclert, Rognlie and Straub, 2024). As a result, profits in the model are acyclical. Turning to the parameters in the Taylor rule, estimation results for the inflation coefficient repeatedly find a value of 2: Clarida, Gali and Gertler (2000), Smets and Wouters (2007), Carvalho, Nechio and Tristao (2021), and Bayer, Born and Luetticke (2024). The standard deviations are relatively tight, following Bayer, Born and Luetticke (2023), since the estimation on a monetary policy shock is not well suited to identify parameters in the Taylor rule; however for the subsequent estimation on the aggregate demand shock the parameters of the Taylor rule are of interest. All autoregressive coefficients have a beta prior with mean 0.5 and standard deviation 0.2. Finally, for the fiscal rules, the Gamma priors on the debt feedback coefficients of government spending and taxes ensure determinacy. The priors for the fiscal rules follow Bayer, Born and Luetticke (2023), with a standard normal prior for the output coefficients. After mode-finding, credible sets are based on a random walk Metropolis-Hastings algorithm.[25]

[24]More in detail, a parameter $\delta_s \propto \delta_2$ is estimated where δ_2 is scaled such that normalization of capital utilization of 1 in steady state is ensured.

[25]For more details as well as diagnostic checks on convergence, see Appendix D.3.

Table 2: Prior and Posterior Distributions of Estimated Parameters

Parameter	Prior			Posterior	
	Distribution	Mean	Std. dev.	HANK	RANK
			Frictions		
δ_s	Gamma	5.00	2.00	4.83 [2.11, 8.51]	4.79 [2.07, 8.46]
ϕ	Gamma	4.00	2.00	3.62 [1.49, 6.66]	2.57 [1.12, 4.64]
κ_Y	Gamma	0.18	0.02	0.173 [0.141, 0.207]	0.197 [0.165, 0.231]
κ_w	Gamma	0.03	0.02	0.027 [0.012, 0.049]	0.023 [0.009, 0.045]
			Taylor rule		
ρ_R	Beta	0.5	0.2	0.99 [0.98, 1.00]	0.97 [0.95, 0.99]
σ_R	Inv. Gam.	0.05	0.02	0.049 [0.030, 0.075]	0.060 [0.034, 0.096]
θ_π	Normal	2.0	0.2	1.95 [1.61, 2.28]	1.95 [1.62, 2.28]
θ_Y	Normal	0.125	0.05	0.126 [0.04, 0.21]	0.125 [0.04, 0.21]
			Fiscal rules		
ρ_G	Beta	0.5	0.2	0.73 [0.32, 0.96]	0.69 [0.30, 0.95]
γ_B^G	Gamma	0.5	0.25	0.31 [0.18, 0.56]	0.25 [0.11, 0.47]
γ_Y^G	Normal	0.0	1.0	0.19 [-0.59, 1.19]	0.04 [-0.64, 0.83]
ρ_τ	Beta	0.5	0.2	0.63 [0.28, 0.88]	0.62 [0.28, 0.87]
γ_B^τ	Gamma	0.5	0.25	0.15 [0.05, 0.30]	0.13 [0.05, 0.26]
γ_Y^τ	Normal	0.0	1.0	2.03 [1.13, 3.08]	1.96 [1.14, 2.91]

Notes: The posterior columns report the posterior mean and 90% credible sets.

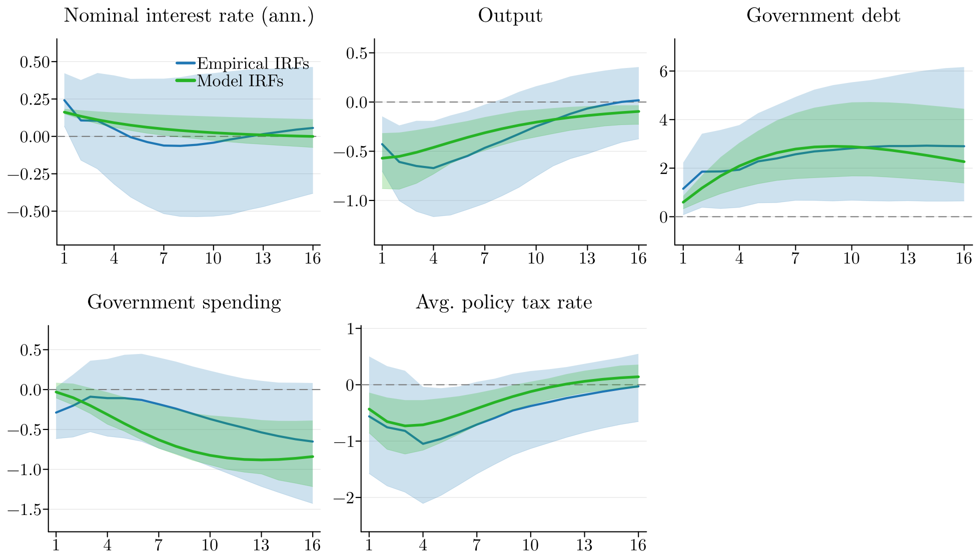
5.3 Parameter Estimates and Model Fit

Figure 5 presents the empirical impulse responses in blue versus the model-implied impulse responses with estimated parameters at their posterior mean as well as 90% credible sets in green. Overall, the model produces a good fit to the empirical evidence, with credible sets almost always covering the empirical median impulse response. Of note is the typical difficulty of DSGE models to produce hump shapes in output endogenously, even though the impulse response of output does not display a strong hump shape.[26]

Column 5 of Table 2 presents the posterior means of the estimated parameters. In general,

[26] Auclert, Rognlie and Straub (2020) show that including a behavioral friction delivers a hump shape, as in the data.

Figure 5: Impulse Response Matching of the HANK Model to a Monetary Policy Shock



Notes: Impulse response functions (IRFs) to a monetary policy shock (posterior mean estimates and 90% credible sets). All variables are matched and displayed in percent deviations from steady state (the interest rate is zero in steady state).

the friction parameters are in line with the New Keynesian DSGE literature, with a relatively flat wage Phillips curve. The Taylor rule parameters are mostly close to the prior means, but the estimated model implies a strong smoothing parameter ρ_R of 0.99, close to the value found in Bayer, Born and Luetticke (2023), who estimate the Taylor rule by impulse response matching on a government spending shock. The robustness check with the demand shock provides more identifying variation for the Taylor rule parameters and yields very similar estimates, providing a consistent picture across estimation results on the Taylor rule (see Table D.2 in the Appendix).

The parameters governing the repayment of debt, γ_B^G and γ_B^τ, show that the main fiscal tool to consolidate debt is government spending: a one percent increase in debt relative to steady state leads to a contemporaneous decline of government spending of $(1-\rho_G)\gamma_B^G = 0.08$ percent, and a 0.06 percent increase in the tax rate. Interestingly, this is in contrast to common practice in many models of monetary policy in the HANK literature, in which taxes (sometimes lump-sum) are often assumed to be the only instrument to finance debt.[27] Furthermore, the pace

[27]See, e.g., McKay, Nakamura and Steinsson (2016), Auclert, Rognlie and Straub (2020), McKay and Wolf (forthcoming). Although the tax rate does at some point increase due to the positive coefficient on debt, in the short run this feedback is fully dominated by the response of the tax rate to output. Indeed, I find in the VAR evidence that the average tax rate eventually increases (Figure B.2 in the Appendix), in line with the HANK model parameter estimates, but with a very long delay.

Table 3: Untargeted Fiscal Moments

Moments	HANK	RANK	Data	Data source
Cumulative tax multiplier	−1.5	−0.3	[−1.0, −3.0]	Ramey (2019), Perotti (2012)
Cumulative spending multiplier	1.3	0.6	[0.6, 2.0]	Ramey (2019)
MPC (quarterly, \$500)	0.2	0.01	0.15–0.25	Havranek and Sokolova (2020)
Avg. tax rate, bottom quintile	17%		15%	CBO & ITEP
Avg. tax rate, middle three quintiles	26%		22%	CBO & ITEP
Avg. tax rate, top quintile	31%		29%	CBO & ITEP

Notes: Consistent with the empirical estimates in Ramey (2019), the cumulative government spending multiplier is computed over five years, and for taxes the peak cumulative multiplier is reported. For details on the average tax rates by percentiles of the income distribution, see Appendix A.2.

of repayment is very slow: after the monetary shock, debt remains elevated for roughly seven years. Finally, the feedback coefficient from output to the tax rate stands out with a value of 2.03. This is evidence of a strong business-cycle stabilization motive of the fiscal authority by exercising countercyclical tax policy. In contrast, the feedback parameter of output on government spending, γ_Y^G, is small and the credible sets comfortably cover zero. All in all, the estimation results support a long and gradual repayment of debt, with government spending as the main margin of adjustment to debt, as well as strong countercyclical tax policy to stabilize economic conditions.

Since the fiscal channel of monetary policy in theory is not confined to models with heterogeneity, in principle it can be analyzed in a RANK economy as well. In order to compare the fiscal channel in HANK versus in RANK, I estimate the corresponding RANK economy using the same impulse response matching procedure and prior distributions. The results for the parameter estimates are shown in column 6 of Table 2 and are generally quite close to the HANK counterpart. However, for the estimated model to constitute an appropriate laboratory to study the fiscal channel, the model should not only fit key impulse responses well, but importantly match moments that determine the effects of fiscal policy. To that end, Table 3 compares key statistics that describe the effects of fiscal policy in the data to those implied by the HANK and RANK models. The marginal propensity to consume (MPC) is the key model statistic governing the Keynesian cross multiplier and zeroes in on one of RANK's main deficiencies in the context of fiscal policy propagation (Bilbiie, 2020; Auclert, Rognlie and Straub, 2024). The summary statistic describing the effects of tax and government spending policy is their cumulative output multiplier.[28] For the estimated model,

[28] Mountford and Uhlig (2009) and Ramey (2019) argue that cumulative multipliers are a more robust description of the data than impact multipliers.

the tax multiplier — the cumulative output response per 1% of output change in tax revenues — is -1.5, and for the government spending multiplier it is 1.3. Both estimates are in line with the ones typically found in the empirical literature surveyed by Ramey (2019) and Perotti (2012). In particular, a tax multiplier that significantly exceeds unity in absolute value has so far eluded DSGE models, yet is key for the analysis here (Ramey, 2019).[29] Consequently, the small tax multiplier is the main impediment of the RANK model for a quantitative analysis of the fiscal channel. In Appendix D.4 I analyze the sensitivity of the multipliers to policy-rule parameters and find that both fiscal output stabilization and debt-financing, of both fiscal instruments, substantially affect and determine the multipliers sizes. This sensitivity further highlights how incorporating systematic fiscal policy rules is of first-order importance in a quantitative analysis. Finally, the calibrated progressivity of the income tax rate provides a reasonable approximation to the tax burden in the data. Progressive income taxation generates automatic income stabilization in HANK, as documented in the empirical evidence. In RANK, though, the effects of progressivity applied to the average household will be close to nil.

The baseline parameter estimates of Table 2 are robust to i), extending the input arguments of the fiscal policy rules, and ii) by utilizing the related but stronger identifying variation from the MBC shock instead (compare Section 3.5). Table D.1 in the Appendix shows that extending the fiscal policy rules to allow for a direct reaction of the fiscal instruments to the interest rate yields an interest rate coefficient close to zero, while leaving the other parameter estimates largely unchanged. These estimates confirm the intuition from the empirical evidence in Section 3.5 that fiscal policy does not react to the level of interest rates. There is some modest evidence that the tax rate systematically reacts to inflation, but the magnitude is economically small and the credible sets of all of the added coefficients cover zero. Moreover, if the fiscal authority is not responding to structural shocks directly, the estimated fiscal rules should be the same conditional on a different shock. Table D.2 shows that the fiscal policy parameter estimates from the demand shock estimation are remarkably similar to the ones reported in the baseline estimation conditional on a monetary policy shock. As hypothesized, due to the significance of the MBC shock in driving business cycles in the U.S., most parameter estimates are more tightly estimated.

Finally, the estimates in Tables 2 and D.1 are corroborated by the evidence in Caldara and Kamps (2017), despite a very different identification strategy for fiscal rule coefficients in a VAR, utilizing technology, oil and monetary shocks. Specifically, they estimate a strong positive output coefficient in the tax rule, alongside a coefficient close to zero on output for

[29] The strong consumption-labor complementarity of GHH preferences leads to high fiscal multipliers as shown by Auclert, Bardóczy and Rognlie (2023). That they lie in the empirical range in this model is due to several model features that dampen them: sticky wages partially translate higher labor demand into increased wage markups, variable capacity utilization allows output to adjust without increases in hours, distortionary taxes absorb part of the consumption feedback, and the Taylor rule crowds out demand via higher real rates.

government spending. What is more, they find no (little) systematic response of government spending (taxes) to the interest rate, while there is some modest response to inflation, consistent with the estimation results presented here. Corsetti, Meier and Müller (2012) and Born and Pfeifer (2014) find (delayed) government spending to be the main fiscal consolidation instrument, in line with my estimates. Furthermore, the insensitivity of government spending to business-cycle conditions is consistent with new data on federal purchases by Cox et al. (2024), showing that spending is granular, volatile, concentrated in long-term contracts, and thus not quickly adjusted.

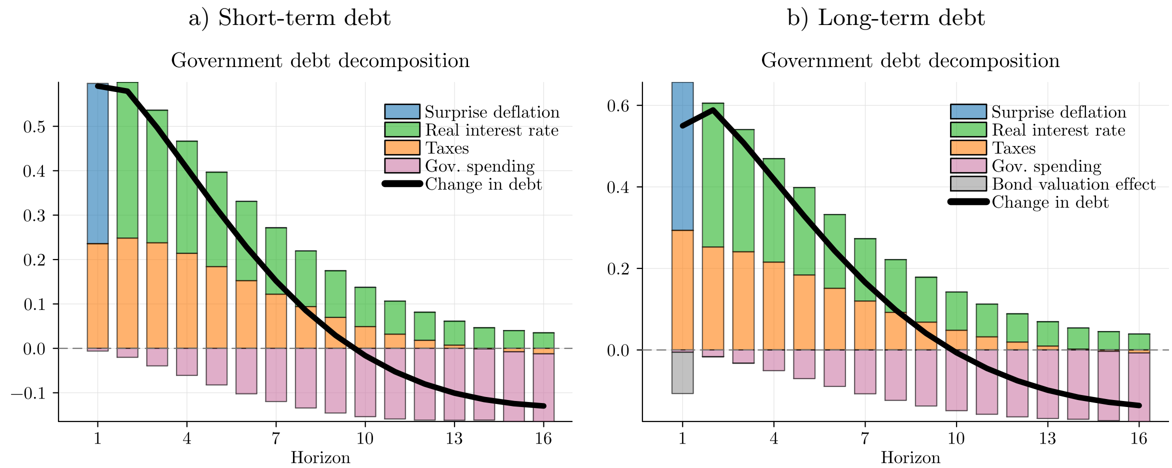
6 Estimated Fiscal Rules and the Fiscal Channel of Monetary Policy

In this section, first, I use the model to decompose the overall fiscal budgetary impact of interest rate changes into its driving components and quantify their relative magnitudes. Second, in a series of counterfactuals, I show how the government's business-cycle stabilization motive shapes the effects of monetary policy. Third, I present a parsimonious fiscal rule with only two policy parameters that provides a convenient, portable specification for systematic fiscal policy for future research on HANK models while delivering a good fit to the data.

6.1 Decomposing the Estimated Fiscal Consequences of an Interest Rate Increase

The empirical evidence presented in Section 3 quantified the overall impact an interest rate increase has on the federal budget. The estimated model allows us now to deconstruct the quantitative relevance the interest rate and the endogenous responses of the fiscal instruments have, respectively, on the federal budget (to first-order). Figure 6 shows the empirically matched change in real government debt after a monetary surprise, decomposed into its drivers. Progressive taxation and expansionary tax policy strongly impacts the federal budget in the form of lower tax revenues, but the real interest rate effect is quantitatively even stronger. While it confirms large fiscal footprints of monetary policy as originally shown in Kaplan, Moll and Violante (2018), importantly, it is the effect of the interest rate on the price level that dominates the dynamics of government debt. The higher debt level results overwhelmingly from the revaluation of debt in real terms, not from higher nominal interest rate payments on rolled-over debt. Therefore, a model with long-term debt does not alter this strong impact of the interest rate on the debt level, as is shown in panel b) of Figure 6. The presence of long-term debt reduces the costs due to higher nominal interest rates and, because the bond price falls, the government's outstanding liabilities decrease in value. However, disciplining the HANK model quantitatively on the empirical effects of monetary

Figure 6: Decomposition of the Change in Real Government Debt Following a Monetary Shock



Notes: Impulse response of the change of real government debt following a 25 bp increase in the annualized nominal interest rate in the estimated HANK model. Panel b) shows the HANK model but reestimated with $\delta_b = 0.05$, implying an average maturity of debt of 5 years (all estimated parameters remain very similar). Percent changes in deviation from steady state.

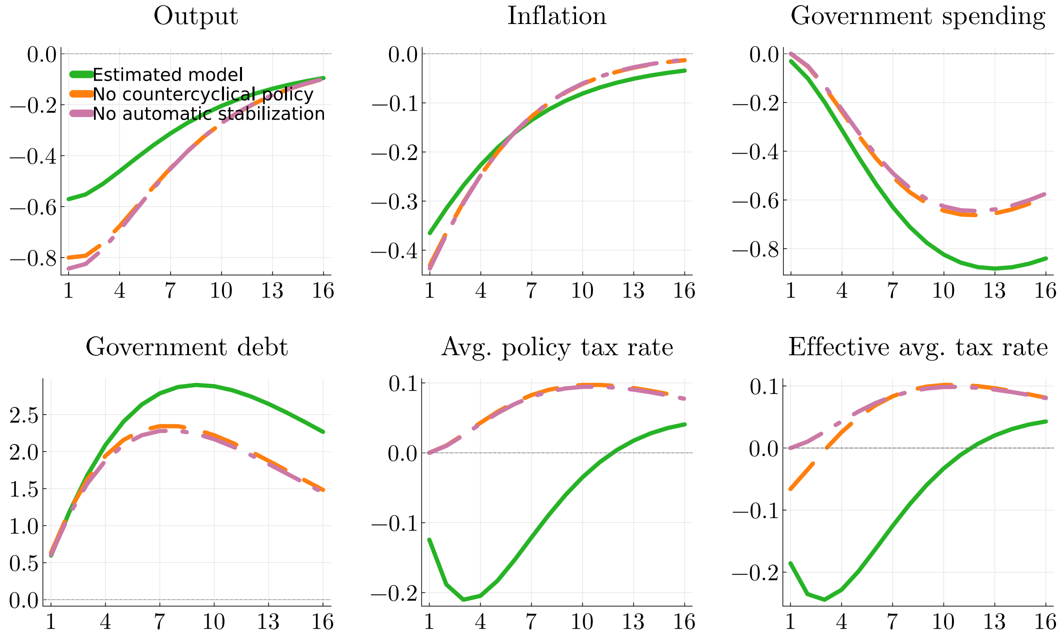
policy shows that the main impact on the government's budget, next to the endogenous reaction of tax revenues, is via the price level, and therefore remains powerful, even if debt is long-term.[30]

Figure 6 makes clear that the government places itself under dual strain after a monetary tightening. In addition to the real interest rate burden, fiscal policy becomes decidedly expansionary: the bars of taxes and government spending show the evolution of the primary surplus, which is negative for the first 6 quarters. Only after this temporary expansionary fiscal stance does a fiscal contraction occur, showing that in the short-run, the path of primary surpluses does not constrain monetary policy. However, the fiscal contraction does occur in net-present value terms, satisfying the intertemporal government budget constraint.[31]

[30] Auclert, Rognlie and Straub (2020) analyze and estimate a HANK model with long-term government debt and argue that monetary policy does not have strong fiscal footprints in their model. However, their fiscal responses to the monetary policy shock are not empirically disciplined, and their empirical evidence relies on Romer and Romer (2004) identification which implies that a $25bp$ interest rate increase lowers inflation by only 0.06%. The empirical evidence presented above (Figure 1) yields a -0.36% fall instead, in line with the recent literature on the effects of monetary policy, see the discussion and references in Section 3.3. Though untargeted, the model matches that well.

[31] The decomposition in Figure 6 reflects a fundamental restriction on the joint path of interest rates, inflation, and primary surpluses, recently emphasized by Caramp and Silva (2023) and Kaplan (forthcoming): with positive government debt, a temporary increase in the nominal interest rate can only persistently lower inflation if accompanied by a fiscal contraction. Consider the forward-iterated government budget constraint, log-linearized and with s_t denoting the primary surplus:

Figure 7: Counterfactual: No Business-Cycle Stabilization Motive of the Government



Notes: Impulse response functions to a monetary policy shock in the HANK model. Y-axis: percent deviations from steady state, except for tax rates, shown in percentage points. X-axis: Quarters. The corresponding RANK results are shown in Figure D.2 in the Appendix.

6.2 Counterfactual Analyses and Policy Implications

Having established that the estimated HANK model is a useful laboratory to quantitatively study the role of fiscal policy in the monetary transmission mechanism, this section quantifies this role via counterfactual scenarios. Since the estimation revealed that the U.S. fiscal authority has a strong business-cycle stabilization motive, a natural question is to assess how this motive shapes the effects of monetary policy. To that end, I apply the following restriction to the parameters of the estimated HANK model: $\gamma_Y^\tau = \gamma_Y^G = 0$, suspending the business-cycle stabilization motive.

The first two rows of Figure 7 present impulse response functions to a monetary policy shock in this counterfactual scenario for the HANK model. The average tax rate does not decline anymore, but instead rises, due to the increase in debt. Government spending is only modestly affected since its evolution is dominated by the high coefficient on debt γ_B^G, i.e., its

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$$B_0 = \sum_{t=0}^{\infty} \exp\left[-\sum_{\tau=0}^{t-1}(r_\tau - \pi_\tau)\right] s_t, \tag{36}$$

where lower-case letters denote log-deviations from steady state (and recall $\bar{R} = \bar{\pi} = 1$). A rise in the real rate can only lower inflation if s_t increases, but this formulation makes it clear that there is no restriction on the timing.

debt repayment motive. As a consequence, output drops by roughly 40% more on impact since the stabilizing, systematic reaction of taxes is missing. The higher tax rates lead to a markedly less pronounced rise in the debt level.

The effective average tax rate is still declining, however, because of progressive taxation: the drop in incomes makes the households face a lower effective tax rate — an automatic stabilization of the tax code (bracket creep). Therefore, in a second counterfactual this automatic stabilization is removed as well, to quantify the total fiscal stabilization effect, both systematic, and automatic. To that end, the level parameter of the tax code, τ_t^l, is used as an instrument to shift the entire tax schedule uniformly to exactly offset bracket creep, and to equate the effective and the statutory tax rates, as would be the case without progressivity.[32] Concretely, the counterfactual is implemented by equating the effective and statutory tax rates, Equations (29a) and (29b), which is achieved simply by requiring the tax level parameter to respond to the income response as well,

$$1 - \tilde{\tau}_t = (1 - \tau_t^l)\mathrm{GI}_t \quad \Rightarrow \quad \tilde{\tau}_t = \tau_t \ \forall t, \tag{37}$$

where the result follows from substitution of Equation (29a). In the linearized model, this eliminates the terms through which income fluctuations move the effective tax rate away from the statutory rate. Removing this automatic stabilizer effect counterfactually reduces output by another 10% relative to the baseline. In the absence of both automatic and systematic fiscal stabilization, the effects of monetary policy on output are thus roughly 50% stronger. Figure D.2 in the Appendix shows that the same counterfactuals in RANK would deliver a −13% and −1% stronger fall in output, respectively, substantially underestimating the effects of the fiscal expansion.

The counterfactual additionally shows that personal income tax changes are estimated to affect inflation mainly through a Keynesian aggregate demand logic, though less than output, consistent with empirical evidence (Cloyne et al. (2023), Mertens and Ravn (2013)). Moreover, the counterfactual highlights that the empirically estimated aggregate effects of monetary policy understate other transmission mechanisms of monetary policy to output and inflation, since the fiscal channel counteracts them. Figure D.3 in the Appendix presents ad-

[32] Importantly, the progressivity parameter τ^p (and hence the steady state) stays unchanged throughout, a key difference to McKay and Reis (2016). They find that aggregate output volatility is essentially unchanged when progressivity is removed. The near-zero net effect arises because two mechanisms roughly cancel: the direct channel — progressive taxes cushioning disposable income fluctuations — is offset by a countervailing effect on monetary transmission. Progressive taxes reduce the sensitivity of the after-tax real return on saving to nominal interest rate changes, rendering monetary policy less effective at stabilizing demand. In an economy without progressive taxation, monetary policy therefore stabilizes more strongly, compensating for the loss of the direct disposable-income channel. The counterfactual considered here does not feature this second channel, since the progressivity parameter τ^p and therefore the after-tax return on saving stay unchanged. Indeed, they show that when monetary policy is accommodative, the countervailing effect weakens and automatic stabilizers have a substantially larger impact on output volatility (their Table XII), consistent with the income-level effect found here.

ditional variables, importantly private consumption and investment, highlighting that private consumption is most affected by the fiscal channel, as opposed to investment. Thus, general equilibrium income and consumption feedbacks are even more important in the monetary transmission mechanisms than previously thought.

All in all, the counterfactual scenarios in the HANK model suggest that, absent the fiscal channel of monetary policy — an endogenous reaction of taxes and spending to economic conditions — output losses induced by a higher interest rate would be up to 50% larger. While an automatic stabilizer effect from taxes has been taken into account, the automatic cyclical transfer response documented in the empirical evidence of Section 3 is likely to strengthen the fiscal offset.

The documented estimated fiscal response over the $1988-2019$ sample need not be representative for every monetary policy contraction. In times of limited fiscal capacity, the dual strain on the federal budget — due to both the real interest rate and fiscal stabilization policy — might not be economically or politically feasible, potentially curtailing the government's ability to stabilize economic conditions. To the extent that limited fiscal space reduces or eliminates fiscal stabilization, the counterfactuals of Figure 7 quantify the resulting higher output costs of interest rate increases and highlight a dependence of the real effects of monetary policy on the fiscal policy response. This dependence renders the fiscal capacity, or "space", of the government an important statistic for the conduct of monetary policy.

6.3 A Parsimonious Description of Systematic Fiscal Policy

The estimated fiscal rules presented in this paper ensure a fiscal response that is in line with the data. Moreover, the previous counterfactuals showed that two parameters dominate the fiscal response: the feedback to debt largely determines the government spending path, while the feedback to output dominates the tax response. Reestimating the baseline HANK model with only those two policy parameters delivers a decent fit to the data (cf. Figure D.5) while yielding a very parsimonious specification of the fiscal policy rules (in log-linearized form):

$$\tilde{\tau}_t = 0.5\tilde{\tau}_{t-1} + 0.67 y_t \tag{38}$$

$$g_t = 0.8 g_{t-1} - 0.07 b_t. \tag{39}$$

The debt-repayment parameter, $-(1-\rho_G)\gamma_B^G = -0.07$ highlights that the fiscal adjustment to deficits is very slow. This is a crucial parameter in any model without Ricardian Equivalence, which often is calibrated due to a lack of empirical evidence. The output coefficient on the tax rate captures succinctly the business-cycle stabilization motive of systematic fiscal policy. These "simple rules" are easily implemented in any DSGE model and are meant to provide the empirical benchmark for the fiscal policy response in models of monetary analysis.

7 Conclusion

This paper studies a Heterogeneous Agent New Keynesian model that allows for a general role of systematic fiscal policy in the monetary transmission mechanism. The model, and crucially the fiscal policy rule parameterization, are empirically disciplined by new evidence on the causal effects of U.S. monetary policy on the full set of fiscal policy instruments. I find that U.S. fiscal policy leans against the effects of monetary policy via countercyclical tax and transfer policies, thereby dampening its contractionary effects. The estimated rules show that systematic fiscal policy does not respond to the interest rate itself, but rather to economic conditions. I use the estimated HANK model to quantify the effects of monetary policy in the absence of the fiscal business-cycle stabilization, which implies output losses would be up to 50% larger.

The fiscal channel has implications for the effects of monetary policy depending on the ability of the government to conduct stabilization policy. If fiscal space is limited, interest rate changes by the central bank could lead to greater output contractions. This result readily connects to the analogous literature that documents that the fiscal multiplier depends on the monetary reaction, which has received empirical support. Moreover, that systematic fiscal policy opposes the interest rate change raises questions concerning optimal policy coordination. On the one hand, countercyclical fiscal policy in response to output-deviations from the steady state could be desirable in general, even if they are induced by monetary policy. In fact, since tax changes are estimated to affect output more than inflation, the fiscal channel seems to improve the inflation-output trade-off for the central bank. On the other hand, by leaning against systematic monetary actions, fiscal policy could be obstructing the central bank in fulfilling its mandate. These appear to be important avenues for further research.

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Supplementary Online Appendix for: Quantifying the Fiscal Channel of Monetary Policy

This Appendix provides (i) a detailed description of all the data used in the paper in Appendix A, as well as Figures on the time series of different tax rates; (ii) robustness as well as additional results from the VAR analysis in Appendix B; (iii) further details on the HANK model in Appendix C; and (iv) further results from the model estimation as well as estimation diagnostics in Appendix D.

Appendix A Detailed Data Description

A.1 Data for VAR Analysis

The variables enter the VAR in log-levels, except for interest rates, tax rates, the Excess bond premium, the Bill share in public debt, the output gap, and the proxy series, which are made commensurable in scale to the other log-transformed variables.

Table A.1: Detailed Description of Data Used in the VAR Analysis

Variable	Description	Notes	Source
Shadow rate	Shadow rate by Wu and Xia (2016)	Extended back to 1980 with the Federal funds rate	FRED (FEDFUNDS) and Wu and Xia (2016)
1-year Treasury yield	Market Yield on U.S. Treasury Securities at 1-Year Constant Maturity		FRED (GS1)
Industrial Production	Industrial Production: Total index		FRED (INDPRO)
Unemployment rate			FRED (UNRATE)
Consumer Price Index	Consumer Price Index (CPI) for All Urban Consumers: All Items in U.S. City Average		FRED (CPIAUCSL)
Excess bond premium	Excess bond premium by Gilchrist and Zakrajšek (2012)		Macrobond Financial AB
Population	Civilian noninstitutional population, 16 years and older		FRED (CNP16OV)
Real par value of debt	Real value of Federal Debt Held by the Public, per capita	Divided by the CPI and population	FRED (FYGFDPUN)
Government spending	Real general government consumption and investment, per capita	Divided by population	FRED (GCEC1)
Federal gov. consumption	Real federal government consumption, per capita	Divided by population	FRED (A957RC1Q027SBEA, A957RG3Q086SBEA)

Federal gov. investment	Real federal government investment, per capita	Divided by population	FRED (A787RC1Q027SBEA, B787RG3Q086SBEA)
State local gov. consumption	Real state and local government consumption, per capita	Divided by population	FRED (A991RC1Q027SBEA, A991RG3Q086SBEA)
State local gov. investment	Real state and local government investment, per capita	Divided by population	FRED (SLINV, B799RG3Q086SBEA)
Real market value of debt	Per capita	Divided by CPI and population	FRED (MVGFD027MNFRBDAL)
Interest payment	Real federal government interest payments, per capita	Divided by CPI and population	FRED (A091RC1Q027SBEA)
Bill share in public debt	Treasury Bills outstanding, divided by all public marketable debt		U.S. Department of Treasury
Unempl. & safety-net support	Personal current transfer receipts: Government social benefits to persons: Unemployment insurance plus Government social benefits to persons: Other[a]	Divided by the CPI and population	FRED (W827RC1, W825RC1)
Transfers, other	Personal current transfer receipts: Government social benefits to persons minus Unempl. & safety-net support	Divided by the CPI and population	FRED (A063RC1)
Average personal income tax rate	Federal personal tax receipts (A074RC1Q027SBEA) divided by Personal income tax base	Personal income tax base is computed as Personal income (PINCOME) minus transfers (A063RC1Q027SBEA) plus social insurance (LA0000121Q027SBEA) (per capita). Follows Mertens and Ravn (2013).	FRED
Average corporate tax rate	Corporate tax income divided by corporate tax base	Corporate tax income (B075RC1Q027SBEA) divided by Corporate profits (CPROFIT) (deflated, per capita). Follows Mertens and Ravn (2013).	FRED
Tax revenues	Real federal tax revenues, per capita	Divided by population	FRED (FGRECPT)
Cycl. adj. tax revenues (CBO)	Real federal tax revenues, cyclically adjusted	Divided by population	Congressional Budget Office
Avg. policy tax rate	Average personal income tax rate	See text for a description	TAXSIM, NBER
Marg. income tax rate	Marginal income tax rate		TAXSIM, NBER
Output	Output gap		Congressional Budget Office
Avg. interest rate on debt	Weighted average interest rate on all outstanding interest-bearing U.S. Treasury securities	Monthly, end-of-month.[b]	U.S. Department of Treasury

Monetary policy proxy	High-frequency yield surprise	First principal component of several high-frequency variables around FOMC announcements	Bauer and Swanson (2023*b*)
Main Business-Cycle shock		See text for details.	Angeletos, Collard and Dellas (2020)

[a] The transfer category "Other" contains safety-net support measures which are regarded as automatic stabilizer and discretionary stimulus packages, see McKay and Reis (2016). The Economic Stimulus Act of 2008 is responsible for large outliers in this category in April to July 2008, which are removed from the time series before entering the analysis.

[b] Jan 1988–Apr 2026. From 2001 onward sourced from the Treasury Fiscal Data API. Pre-2001 values extracted from Monthly Statements of the Public Debt, Table I, via text parsing (1997–2000) and Optical Character Recognition of scanned documents (1988–1996). Three months (Sep 1992, Jan–Feb 1998) are linearly interpolated due to missing or corrupted source PDFs.

A.2 Data for Model Calibration and Validation

The model is calibrated on the post-Volcker disinflation sample, consistent with the empirical analysis. Unless otherwise noted, this implies the sample 1984 – 2019. The data sources for the calibration are the following (where applicable, Fed. Reserve St. Louis FRED database mnemonics in parentheses):

1. **Capital to output ratio**: Annual net stock of fixed assets (K1TTOTL1ES000) divided by annual GDP. GDP is the sum of private consumption (PCEC), investment (GPDI), and government consumption and investment (GCE).

2. **Liquid assets to capital ratio**: Government debt, privately held by domestic investors (FDHBPIN minus FDHBFIN), divided by capital.

3. **Wealth share**: World Inequality Database: `https://wid.world/country/usa/`. This database builds on e.g. Piketty and Saez (2003) and Saez and Zucman (2016).

4. **Government spending to output ratio**: Government consumption and investment (GCE) divided by GDP.

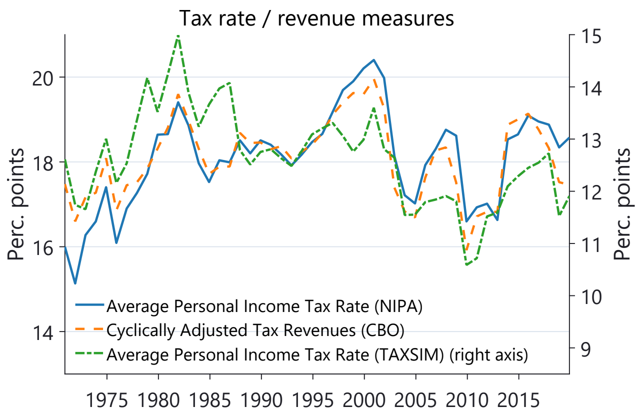
5. **Tax progressivity** The parameter is the time series average of the statistic, using average marginal and average tax rates: $(AMTR - ATR)/(1 - ATR)$, which equals for the Heathcote, Storesletten and Violante (2017) tax system the parameter capturing the curvature of the tax function. Available 1984 – 2017.

6. **(Gross) Nominal rate** Money Zero Maturity Own Rate (MZMOWN) minus Inflation (GDPDEF) (since the model assumes a zero inflation steady state) equals 0.1%.

For the average tax rate statistics by income percentiles in Table 3, state and local effective tax rates are drawn from five editions of Institute on Taxation and Economic Policy (ITEP) "Who Pays?" report (tax years 2002, 2007, 2013, 2015, and 2018), averaged across editions and added to federal series from the Congressional Budget Office (CBO) November 2022 report "The Distribution of Household Income, 2019". The ITEP estimates are the most comprehensive publicly available source for state and local tax incidence across the full income distribution, and the stability of the national average rates across editions (ranging from 10.9 to 11.4 percent for the lowest quintile) suggests the simple average is a reasonable approximation. However, several limitations apply. First, ITEP itself cautions against direct cross-edition comparisons, as methodological refinements to its microsimulation model have evolved over time. Second, ITEP's income concept is narrower than the CBO's. Third, the CBO federal series runs annually from 1984 to 2019, while the ITEP state and local series consists of only five snapshot years. However, Fleck et al. (2025) independently find that state and local taxes have remained relatively constant over the same sample period.

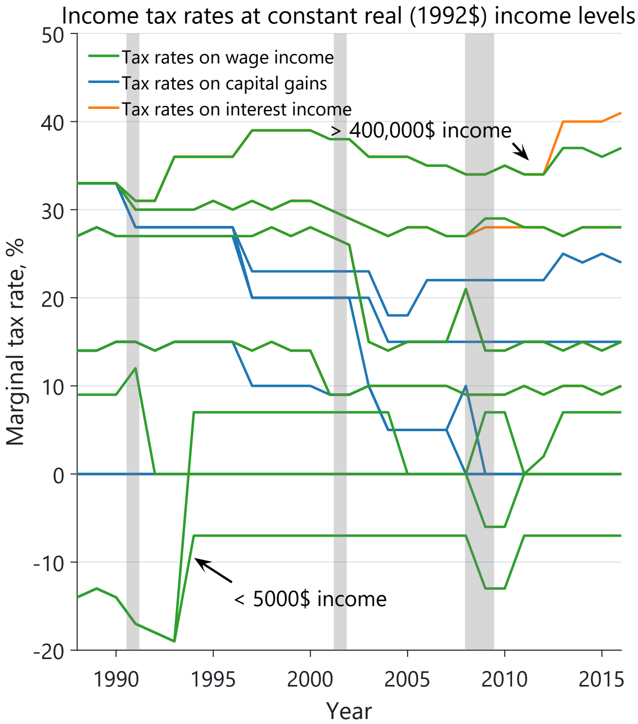
A.3 Variation in Tax Policy

Figure A.1: Changes in the Tax Code and Comparison of Tax Rate Measures



Sources: NIPA, CBO, TAXSIM, and own calculations. Cyclically adjusted tax revenues in percent.

Figure A.2: Changes in the Tax Code for Different Income Levels

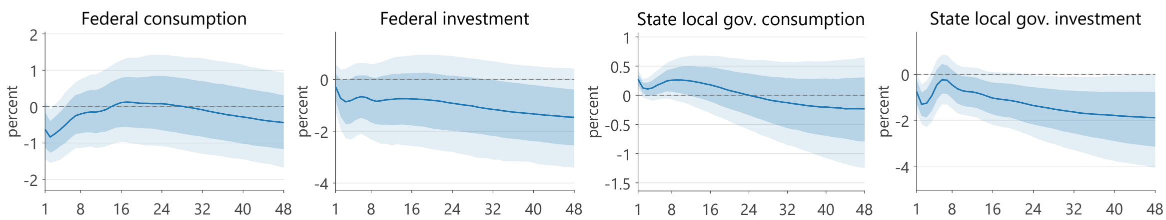


Source: TAXSIM, and own calculations.

Appendix B Additional VAR Results and Robustness

B.1 Additional Results

Figure B.1: MF-BVAR: Responses of Government Spending Components

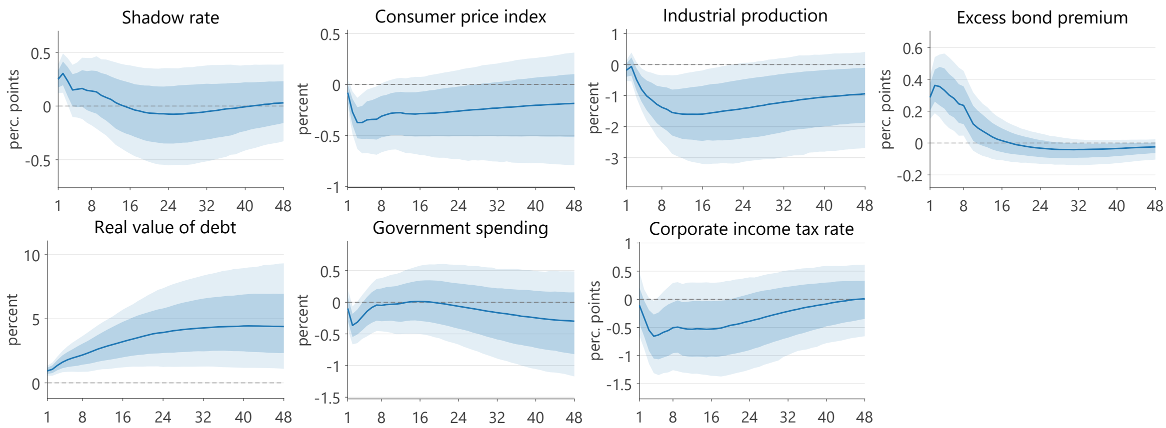


Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.2: MF-BVAR (Quarterly-Annual): 10-Year Responses of Tax Rates

Notes: Impulse response functions to a 25bps monetary shock (panel 1), or to the MBC shock (panel 2). Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

Figure B.3: MF-BVAR: Response to a Monetary Policy Shock with Average Corporate Income Tax Rate

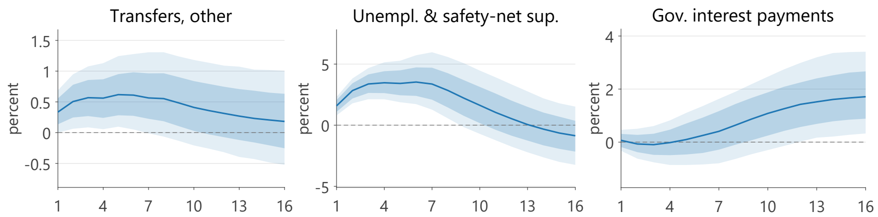


Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.4: MF-BVAR (Quarterly-Annual): Marginal Income Tax Rate

Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

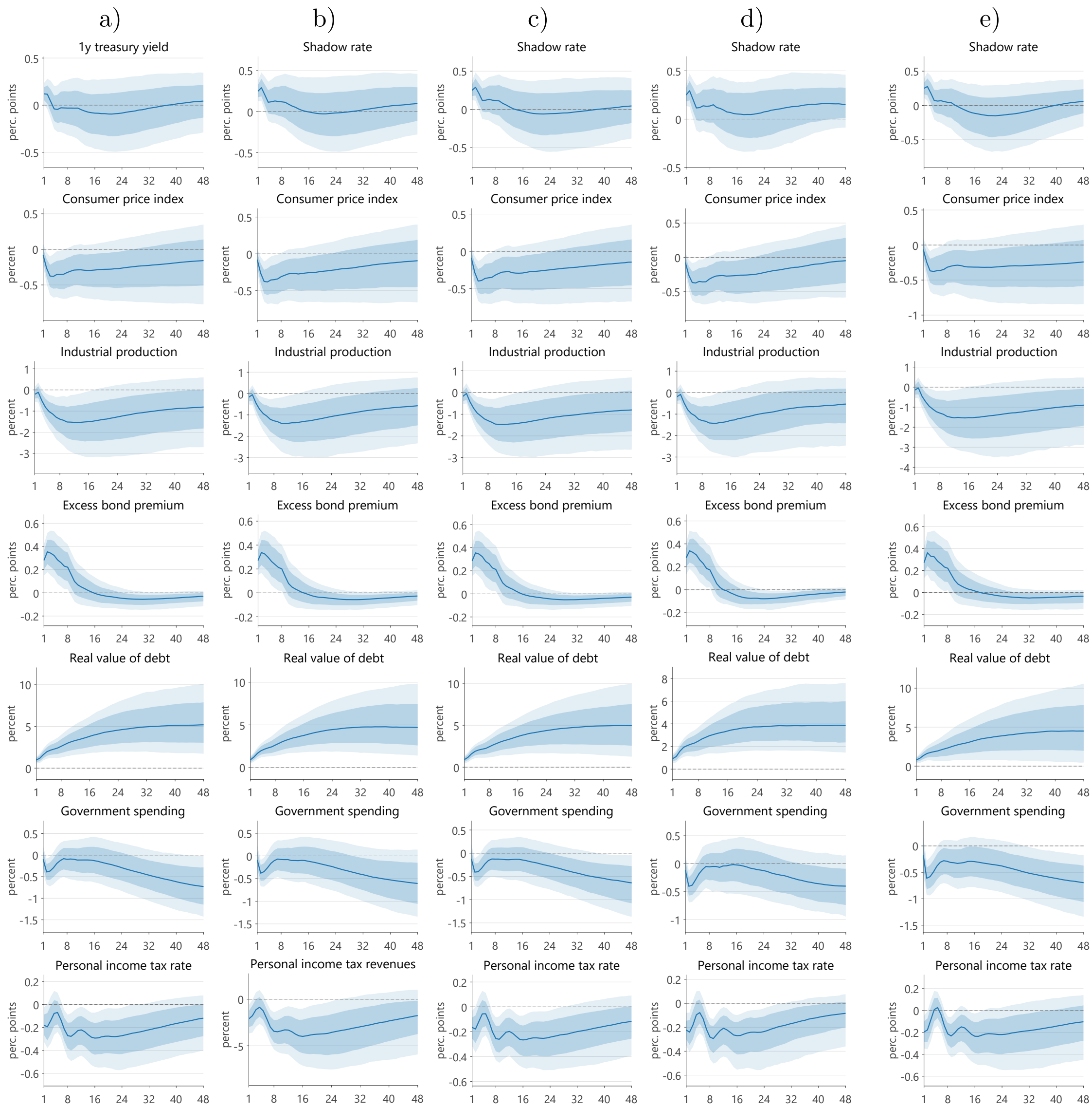
Figure B.5: MF-BVAR: Transfer and Interest Payment Responses to the MBC Shock



Notes: All three variables have been added to the baseline MBC model described in Section 3.5 one by one. Impulse response functions to a one standard deviation shock in the proxy. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

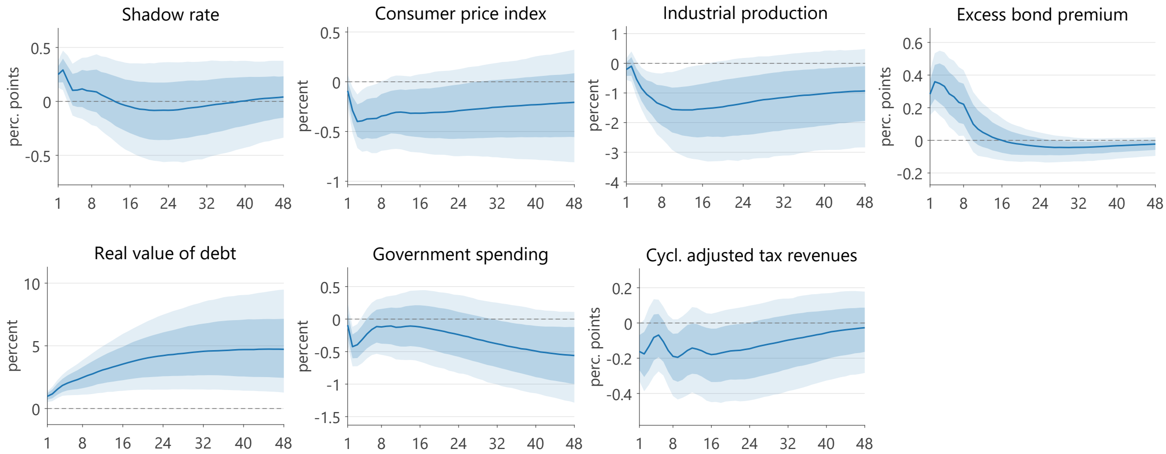
B.2 Robustness Results

Figure B.6: MF-BVAR: Robustness of Baseline Results



Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months. Column a) uses the 1-year Treasury yield instead of the shadow rate; column b) replaces the average tax rate with federal tax revenues. Column c) includes a dummy for a political party in power, column d) instead a dummy for the senate majority. Column e) shows the ZLB robustness check; the sample stops in 2010m12, consistent with Swanson and Williams (2014) who find that monetary policy was first constrained in the beginning of 2011.

Figure B.7: MF-BVAR: Robustness Exercise with Cyclically Adjusted Federal Tax Revenues



Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.8: MF-BVAR (Quarterly-Annual): Robustness to a Constant Calendar Year Tax Rate

Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

Figure B.9: MF-BVAR (Quarterly-Annual): Zero Restriction on Contemporaneous Tax Response

Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

Appendix C HANK Model Details

C.1 Equilibrium Definition

Definition 1. A *Sequential competitive equilibrium with recursive individual planning* for the present model is a sequence of value functions $\{V_t^a, V_t^n\}$ with associated policy functions $\{x_{a,t}^*, x_{n,t}^*, b_{a,t}^*, b_{n,t}^*, k_t^*\}$, sequences of aggregate states $\{\Theta_t, R_t^b, \epsilon_t^R\}$, aggregate capital and labor supplies $\{K_t, N_t\}$, and prices $\{w_t, w_t^F, \Pi_t^F, \Pi_t^U, q_t, q_t^B, r_t^k, \pi_t, \pi_t^w\}$, such that, for all t:

1. Given the functional $\mathcal{W}_{t+1}$ for the continuation value and period-t prices, the value functions $\{V_t^a, V_t^n\}$ are a solution to the Bellman equation 13 with associated policy functions $\{x_{a,t}^*, x_{n,t}^*, b_{a,t}^*, b_{n,t}^*, k_t^*\}$.

2. Distributions of wealth and income evolve according to households' policy functions.

3. The labor, the final goods, the bond, the capital, and the intermediate goods market clear in every period, interest rates on bonds are set according to the central bank's Taylor rule, and fiscal policies are set according to the fiscal rules.

4. Expectations are model consistent.

I solve for the state-space solution of the system of non-linear difference equations. Since the problem is high-dimensional, the solution requires approximations. The method in Bayer and Luetticke (2020) reduces the dimensionality after solving for the stationary equilibrium (i.e., without aggregate risk) but before perturbing the system. In addition, after having solved the model once (to first order around a zero-inflation steady state, as in Schmitt-Grohé and Uribe (2004)) knowledge of the dynamics of the system can be used to further reduce the dimensionality. This is the reduction step described in Bayer, Born and Luetticke (2024), making estimation of the model feasible.

C.2 Long-Term Government Debt Extension

This section extends the baseline HANK model to allow the government to issue long-term bonds, following the standard geometric maturity approach (Woodford (2001), Bayer, Born and Luetticke (2023)). Each government bond pays a fixed nominal coupon of 1 per period and retires (without repaying principal) with probability δ_B each period, yielding an average maturity of $1/\delta_B$ periods. A bond issued k periods ago is equivalent to $(1-\delta_B)^k$ newly issued bonds, so the market value of outstanding bonds suffices to track the entire maturity structure. Bonds trade at nominal price q_t^B.

Bond pricing. The bond price q_t^B is determined by the no-arbitrage condition

$$R_{t+1}^b \, q_t^B = \mathbb{E}_t \left[q_{t+1}^B (1-\delta_B) + 1 \right], \tag{C.1}$$

where R_{t+1}^b is the short-term nominal interest rate set by the central bank in Equation (28). At the beginning of the next period, each surviving bond (probability $1-\delta_B$) is worth q_{t+1}^B, and the holder collects a coupon of 1. The expected return on holding the bond must equal the short-term rate.

Valuation effects. With long-term debt, unexpected changes in interest rates move bond prices and create capital gains or losses. The realized excess return on the outstanding bond portfolio, scaled by the real value of debt, defines the valuation effect:

$$\Pi_t^B = \frac{B_t}{\pi_t} \left[(1-\delta_B) \frac{q_t^B}{q_{t-1}^B} + \frac{1}{q_{t-1}^B} - R_t^b \right]. \tag{C.2}$$

The term in brackets compares the realized gross return—coupon $1/q_{t-1}^B$ plus the capital gain on the surviving fraction $(1-\delta_B)\, q_t^B / q_{t-1}^B$—to the short-term rate R_t^b. When interest rates rise unexpectedly, bond prices fall, $\Pi_t^B < 0$, and the government "gains" at bondholders' expense, and vice versa. The valuation gains or losses Π_t^B accrue to entrepreneurs as part of their profit income, following Bayer, Born and Luetticke (2023).

Government budget constraint. The government budget constraint (32) generalizes to

$$B_{t+1} = G_t - T_t + \frac{R_t^b}{\pi_t} B_t + \Pi_t^B, \tag{C.3}$$

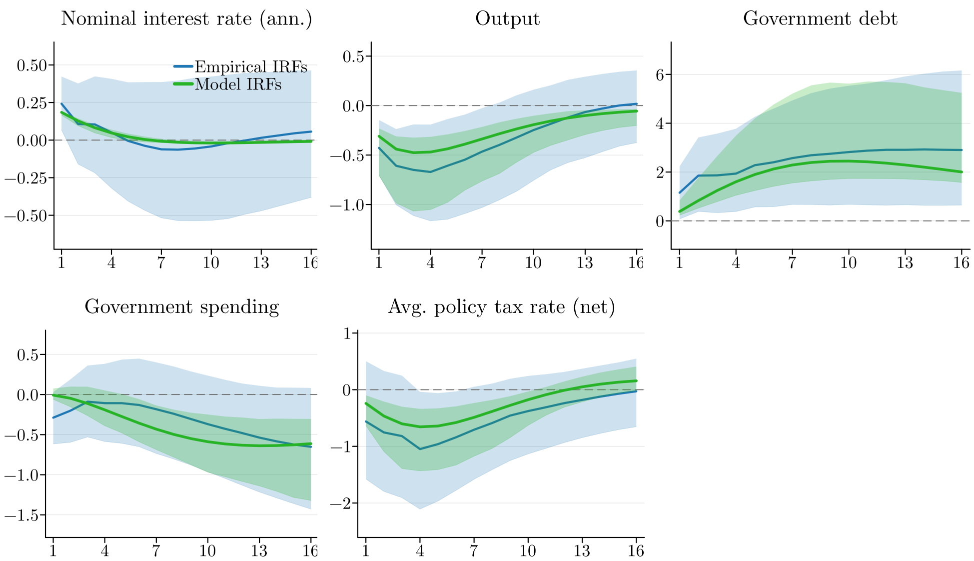
where B_t denotes the real market value of outstanding government debt. The additional term Π_t^B captures the valuation effect: a rise in the bond price (driven by lower expected future rates) increases the market value of the government's outstanding liabilities, tightening the budget constraint. When $\delta_B = 1$, all bonds mature after one period; this case therefore nests the baseline one-period bond.

Appendix D Additional Model Estimation Details and Results

D.1 RANK Results

The RANK economy requires a recalibration to hit the same calibration targets as the HANK model. $\beta = 0.9855$ yields the capital to output ratio $K/Y = 2.83$, and $\bar{\tau} = 0.195$ gives $G/Y = 19\%$. Since the calculation of the duration of average constant prices involves β, $\kappa = (1-\lambda)(1-\lambda\beta)/\lambda$, the prior means for price and wage stickiness have been adjusted accordingly, to be comparable to the HANK economy.

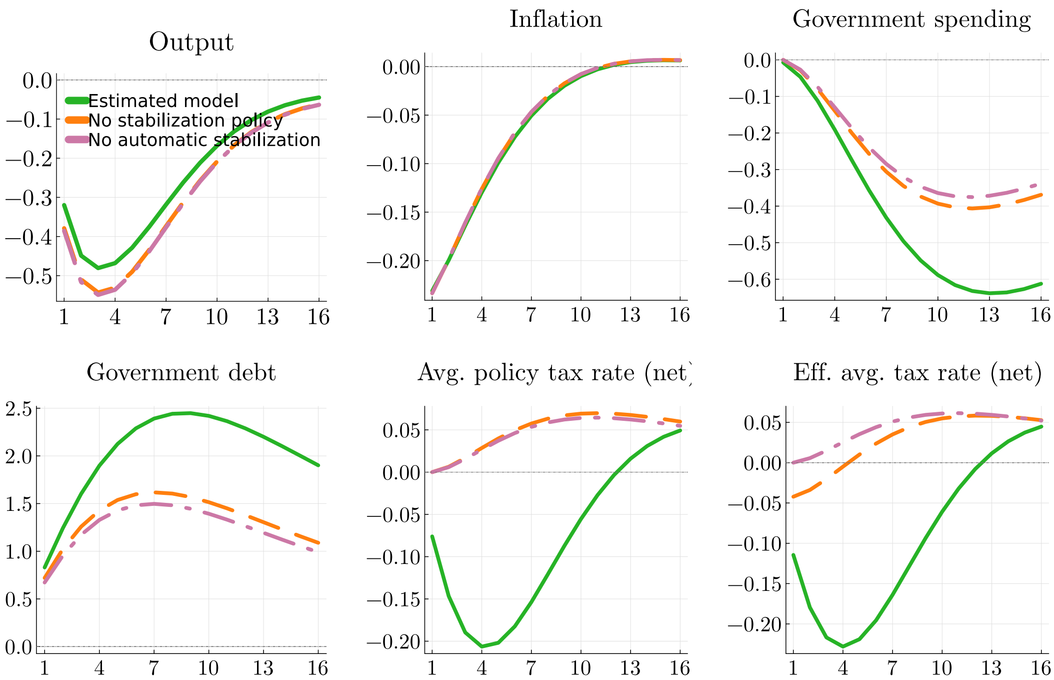
Figure D.1: Impulse Response Matching of the RANK Model to the Monetary Shock



Notes: Impulse response functions to the monetary shock. Model IRFs feature parameters evaluated at the mode. The average tax rate is converted from the empirical analysis to percent deviations from steady state.

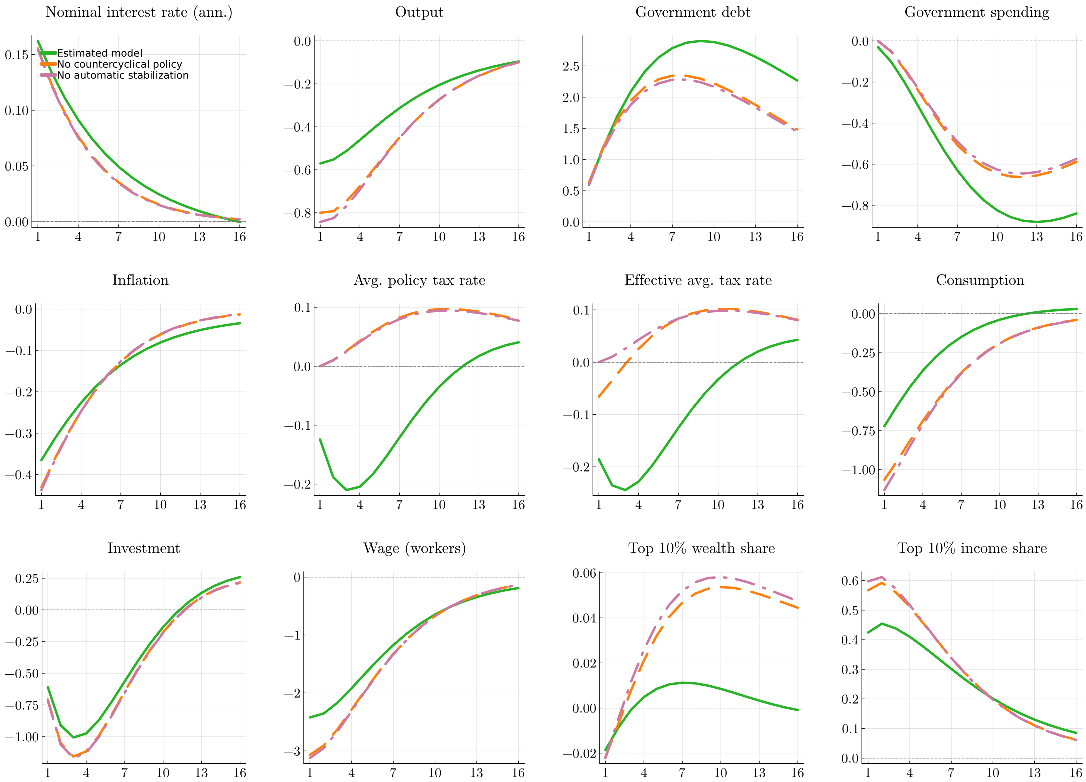
D.2 Robustness and Additional Results

Figure D.2: Counterfactual: No Business-Cycle Stabilization Motive of the Government (RANK)



Notes: Impulse response functions to a monetary policy shock in the RANK model. Y-axis: percent deviations from steady state, except for the tax rates, shown in percentage points. X-axis: Quarters.

Figure D.3: Counterfactuals: Additional Responses in HANK



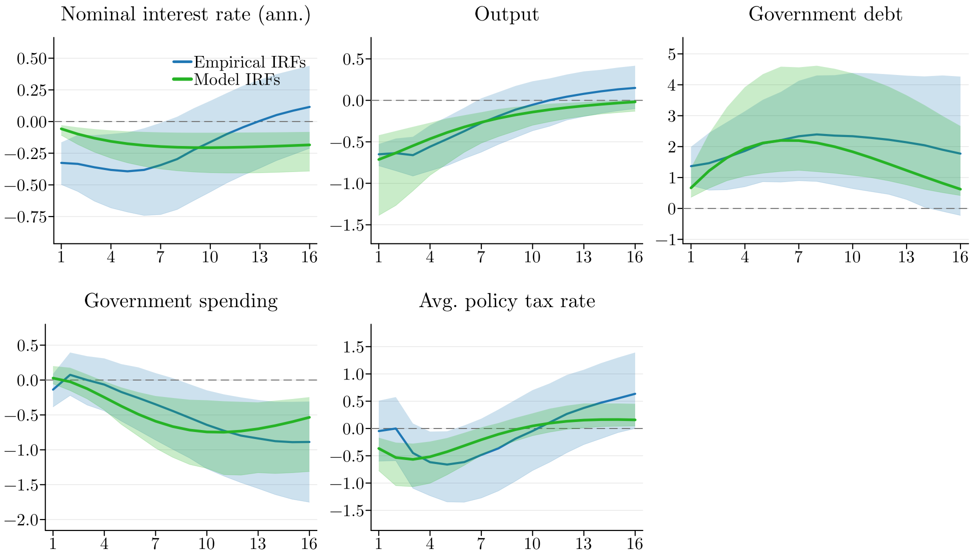
Notes: Impulse response functions to a monetary policy shock in the HANK model. Y-axis: percent deviations from steady state, except for the interest rate, tax rates, and shares, shown in percentage points. X-axis: Quarters.

Table D.1: Estimation Results, Extended Fiscal Policy Rules

	Baseline	Interest rate coefficient	Inflation coefficient
(A.) Tax Rule			
γ_B^τ	0.15	0.16	0.15
	[0.05, 0.30]	[0.06, 0.32]	[0.06, 0.28]
γ_Y^τ	2.03	2.00	1.78
	[1.13, 3.08]	[1.06, 3.04]	[0.76, 2.87]
γ_π^τ			0.72
			[−0.82, 2.25]
γ_R^τ		−0.29	
		[−1.82, 1.24]	
(B.) Govern. Spending Rule			
γ_B^G	0.31	0.32	0.35
	[0.18, 0.56]	[0.17, 0.61]	[0.19, 0.72]
γ_Y^G	0.19	0.10	0.13
	[−0.59, 1.19]	[−0.74, 1.16]	[−0.97, 1.49]
γ_π^G			0.24
			[−1.30, 1.71]
γ_R^G		−0.34	
		[−1.66, 0.83]	

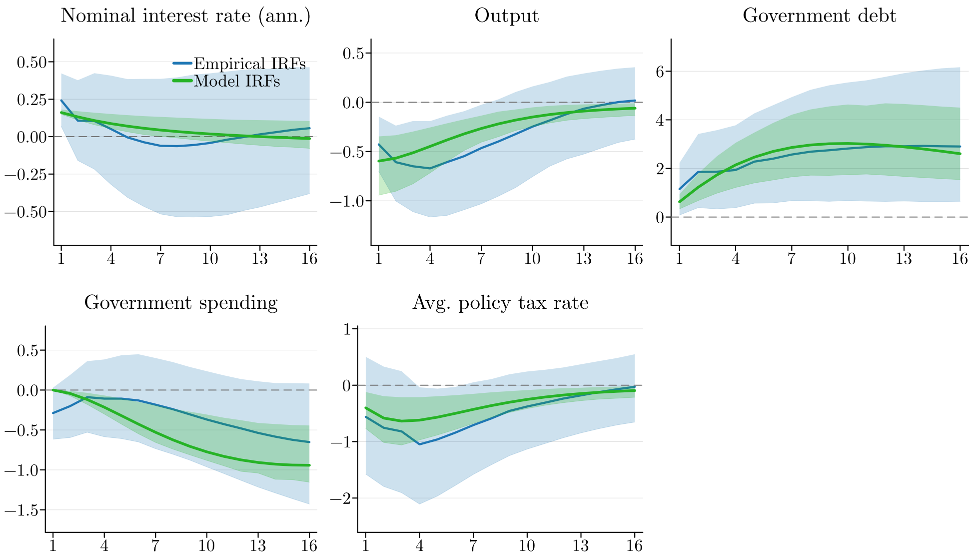
Notes: Posterior means and 90% credible sets from the monetary policy shock estimation. The baseline column repeats the fiscal rule coefficients from Table 2. Each extension column adds the indicated coefficient to the baseline fiscal rules.

Figure D.4: Impulse Response Matching of the HANK Model to the MBC Shock



Notes: Impulse response functions (IRFs) to the MBC shock (posterior mean estimates and 90% credible sets). All variables are matched and displayed in percent deviations from steady state (the interest rate is zero in steady state).

Figure D.5: Impulse Response Matching of the HANK Model with Simple Fiscal Rules



Notes: Impulse response functions (IRFs) to a monetary policy shock for the HANK model with simple fiscal rules (posterior mean estimates and 90% credible sets). All variables are matched and displayed in percent deviations from steady state (the interest rate is zero in steady state).

Table D.2: Prior and Posterior Distributions of Estimated Parameters, Demand Shock

	Prior			Posterior
Parameter	Distribution	Mean	Std. dev.	Posterior Mean (MBC shock)
		Frictions		
δ_s	Gamma	5.00	2.00	5.26
				[2.43, 9.00]
ϕ	Gamma	4.00	2.00	4.05
				[1.81, 7.28]
κ_Y	Gamma	0.18	0.02	0.179
				[0.148, 0.212]
κ_w	Gamma	0.03	0.02	0.043
				[0.024, 0.068]
		Taylor rule		
ρ_R	Beta	0.5	0.2	0.98
				[0.97, 0.99]
θ_π	Normal	2.0	0.2	1.90
				[1.55, 2.24]
θ_Y	Normal	0.125	0.05	0.13
				[0.05, 0.21]
		Exogenous demand shock process		
ρ_A	Beta	0.5	0.2	0.95
				[0.92, 0.98]
σ_A	Inv. Gamma	0.05	0.02	0.08
				[0.04, 0.13]
		Fiscal rules		
ρ_G	Beta	0.5	0.2	0.75
				[0.43, 0.95]
γ_B^G	Gamma	0.5	0.25	0.42
				[0.23, 0.75]
γ_Y^G	Normal	0.0	1.0	-0.16
				[-0.81, 0.80]
ρ_τ	Beta	0.5	0.2	0.69
				[0.40, 0.87]
γ_B^τ	Gamma	0.5	0.25	0.21
				[0.08, 0.40]
γ_Y^τ	Normal	0.0	1.0	1.65
				[0.89, 2.54]

Notes: The posterior column reports the posterior mean and 90% credible sets.

D.3 Estimation Details and Diagnostics

The parameters of the HANK and RANK models are estimated using the Random Walk Metropolis-Hastings algorithm with a multivariate normal as the proposal distribution. After an extensive mode search, a single chain of 450,000 draws from the posterior distribution is used to compute the posterior statistics (discarding 50,000 draws as burn-in). The acceptance rates for all of the models considered range between 20 and 30 percent. Table D.3 reports Geweke (1992) convergence statistics that test the equality of means of the first 10 percent of draws from the posterior distribution compared to the last 50 percent. If the two samples are drawn from the stationary distribution of the chain, the two means are equal and the statistic is asymptotically standard normally distributed. Hence, large p-values indicate convergence. In addition, Figure D.6 presents trace plots for all estimated parameters of the baseline model.

Table D.3: Geweke (1992) Convergence Statistics

Parameter	HANK (baseline)		RANK		HANK (MBC shock)		HANK (simple rules)		HANK (long-term debt)	
	z-stat	p-value	z-stat	p-value	z-stat	p-value	z-stat	p-value	z-stat	p-value
δ_s	-0.14	0.89	0.83	0.41	0.36	0.72	-0.48	0.63	1.21	0.22
ϕ	-0.17	0.87	-1.11	0.27	-1.33	0.18	1.17	0.24	-0.90	0.37
κ_Y	0.78	0.44	1.17	0.24	-1.28	0.20	1.63	0.10	-0.05	0.96
κ_w	0.64	0.52	-0.73	0.47	-1.50	0.13	0.04	0.97	-2.06	0.04
ρ_A	–	–	–	–	-1.16	0.25	–	–	–	–
σ_A	–	–	–	–	0.00	1.00	–	–	–	–
ρ_R	0.38	0.70	-1.02	0.31	-0.26	0.79	0.44	0.66	0.60	0.55
σ_R	-0.46	0.64	1.38	0.17	–	–	-0.59	0.56	-0.61	0.54
θ_π	0.59	0.55	0.37	0.71	-1.48	0.14	-0.07	0.95	-0.17	0.86
θ_Y	0.47	0.64	-0.24	0.81	1.09	0.28	-0.35	0.73	0.26	0.79
ρ_G	-1.40	0.16	0.29	0.77	-0.13	0.89	0.07	0.94	1.21	0.23
γ_B^G	-0.31	0.76	0.20	0.84	-1.55	0.12	-0.82	0.41	-0.65	0.52
γ_Y^G	-0.18	0.86	2.13	0.03	-0.30	0.77	–	–	0.02	0.98
ρ_τ	-1.58	0.11	1.08	0.28	-1.22	0.22	-0.66	0.51	0.49	0.63
γ_B^τ	-1.66	0.10	-0.24	0.81	-1.21	0.23	–	–	-0.67	0.51
γ_Y^τ	-1.50	0.14	-1.13	0.26	-1.45	0.15	-1.99	0.05	-2.16	0.03

Notes: Test of the equality of means of the first 10 percent of draws from the posterior distribution compared to the last 50 percent. Large p-values indicate convergence.

D.4 Multiplier Sensitivity to Policy Rule Parameters

This subsection analyzes how the cumulative output multipliers for government spending and taxes depend on the aggregate parameters of the fiscal and monetary policy rules. Each of the five parameter pairs – (ρ_R, θ_π), $(\rho_\tau, \gamma_B^\tau)$, $(\gamma_Y^\tau, \gamma_\pi^\tau)$, (ρ_G, γ_B^G), $(\gamma_Y^G, \gamma_\pi^G)$, $(\gamma_R^G, \gamma_R^\tau)$ – is varied jointly within ranges roughly spanning the posterior credible sets, holding all other parameters at their posterior mean, and the cumulative multiplier over $H = 20$ quarters is computed on a two-dimensional grid.[33] Figures D.7 and D.8 display the resulting surfaces for the government spending and tax multipliers, respectively.

The spending multiplier is most sensitive to the output feedback of the tax rule, γ_Y^τ: a government spending increase that raises output is endogenously countered by a tax increase when γ_Y^τ is large, reducing the multiplier. How a deficit is financed also matters: higher tax persistence ρ_τ and stronger debt feedback of spending γ_B^G both dampen the multiplier by unwinding the fiscal expansion more quickly. For the tax multiplier, the picture is similar but with the roles reversed: the spending rule's output feedback γ_Y^G and especially the debt feedback γ_B^G are the dominant parameters, as the endogenous spending response to rising debt offsets the stimulus from a tax cut. In addition, the monetary rule matters more for the tax multiplier than for spending, consistent with taxes relying more strongly on general equilibrium effects: higher interest rate smoothing ρ_R makes the monetary offset more persistent, compressing the tax multiplier. Nonetheless, analysis reveals a first-order role of the systematic component of fiscal policy in the determination of the size of multipliers.

[33] The multipliers are insensitive to plausible variations in θ_Y, therefore this parameter is omitted.

Figure D.6: Trace Plots, Baseline Model

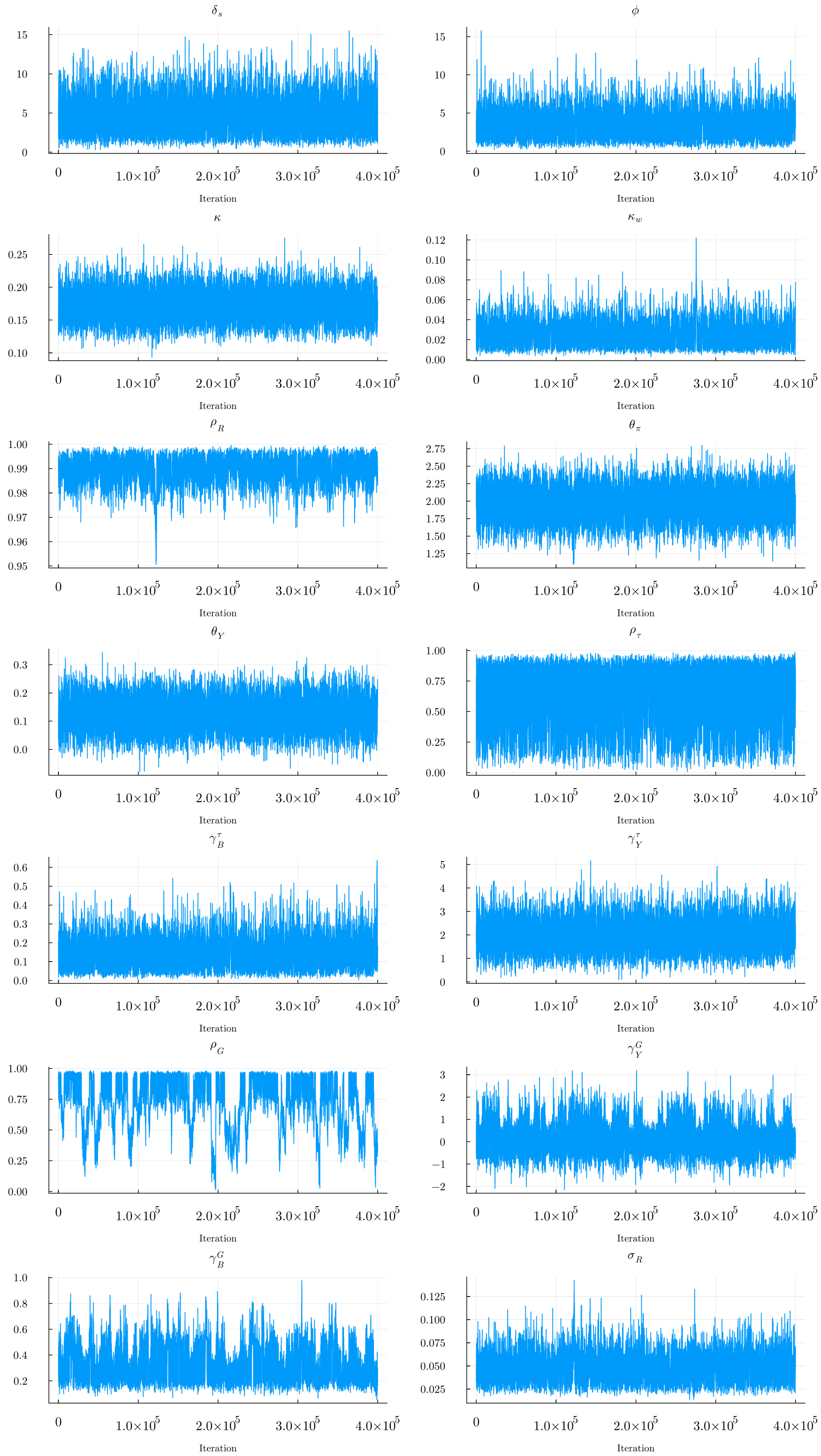
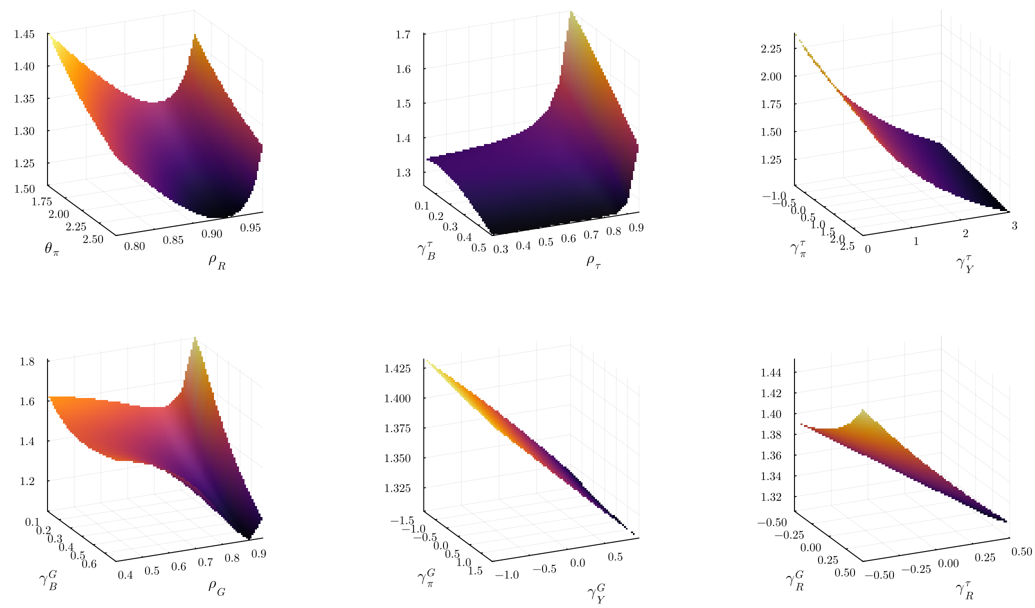
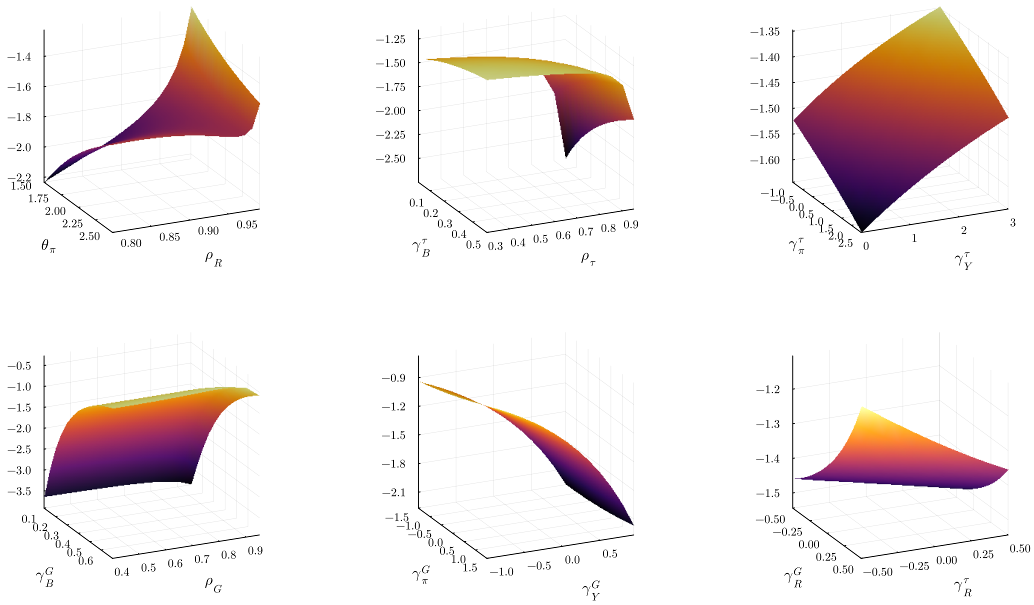


Figure D.7: Sensitivity of the Cumulative Government Spending Multiplier to Policy Rule Parameters



Notes: Each panel shows the cumulative government spending multiplier (over $H = 20$ quarters) as a function of two policy rule parameters.

Figure D.8: Sensitivity of the Cumulative Tax Multiplier to Policy Rule Parameters



Notes: Each panel shows the cumulative tax multiplier (over $H = 20$ quarters) as a function of two policy rule parameters.