

Quantifying the Fiscal Channel of Monetary Policy*

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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 investigates the fiscal reaction by presenting new evidence on the effects of U.S. monetary policy on fiscal policy instruments. Subsequently, it estimates a Heterogeneous Agent New Keynesian model with flexible fiscal feedback rules to match and interpret the empirical results. I find that U.S. 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 one-third more contractionary. As a result, the fiscal channel renders the effects of monetary policy state-dependent on the fiscal capacity for stabilization policy.

Keywords: Macroeconomic policy, HANK, monetary fiscal interaction, Impulse Response Matching

JEL Codes: E21, E52, E60, E63

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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?

I address this question by presenting new evidence on the dynamic causal effects of U.S. monetary policy on the complete set of fiscal variables utilizing vector autoregressions. The estimated impulse response functions then serve as the macroeconomic 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 thus empirically disciplined by 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 increase in the government debt level, a fall in the income tax rate with a delay of around a year, and a slow, gradual fall in government spending. Second, the estimated fiscal feedback rules in the HANK model reveal that the fiscal reactions are not systematic responses to the interest rate. Instead, the income tax rate responds countercyclically to economic conditions, while government spending is mainly adjusted to stabilize the debt level. Moreover, government spending is estimated to be largely insensitive to economic conditions. Third, the total systematic fiscal response shapes the aggregate effects of monetary policy substantially by partially offsetting the monetary-induced output losses. A counterfactual exercise shows that without the fiscal stabilization of economic activity, the effects of monetary policy would be roughly one-third more contractionary. This implies that the fiscal channel renders the effects of monetary policy state-dependent on the fiscal capacity of the government to run deficits in response to higher interest rates, much as the fiscal multiplier is known to be dependent on the monetary reaction.

¹See Caramp and Silva (2023) for the dependence of the representative agent New Keynesian model on the fiscal reaction and the related discussion in Kaplan (2025).

More in detail, the key objects of interest for the characterization of a fiscal channel of monetary policy are the systematic fiscal policy rules governing 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 (2023a) in a mixed-frequency vector autoregressive (VAR) model that combines monthly macroeconomic data with quarterly fiscal variables to alleviate time aggregation bias. In the baseline VAR model, government debt, spending, and the average tax rate are added to a standard monetary model, as in, e.g., Gertler and Karadi (2015).

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 somewhat with a delay of about two years. Adding transfers to the model shows that unemployment and safety-net payments increase significantly, in line with an increase in the unemployment rate, but quite modestly in size. By exploiting an average tax rate measure that by construction eliminates variation in the income distribution and therefore isolates tax rate changes, a fall in this measure implies that the U.S. average tax rate falls after an interest rate hike. Moreover, I show that the documented fiscal responses to an aggregate demand shock look very similar (using the “Main Business-cycle shock” by Angeletos, Collard, and Dellas (2020)), validating the generality of the estimated fiscal reaction and highlighting that fiscal policy responds not to the higher interest rate itself, but it’s macroeconomic consequences. In fact, 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 interest rate costs does not play a first-order role in the fiscal channel of monetary policy.

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 the fiscal behavior conditional on a monetary shock by revealing the roles of 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, 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. In this pursuit, 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. The burgeoning literature on Heterogeneous Agent New Keynesian models made

important advances in this regard, with Kaplan, Moll, and Violante (2018) showing that HANK models imply very different monetary transmission than the previous representative agent literature, which has found empirical support.² Furthermore, Auclert, Rognlie, and Straub (2018), Kaplan and Violante (2014), and Kaplan and Violante (2022) 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 redistributive 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 Representative Agent New Keynesian (RANK) model and show 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, 2010), which in this application is better suited than likelihood-based full-information estimation, for three reasons. First, there is a broad consensus that U.S. monetary policy experienced a regime change in the early 1980s, rendering the sample short.³ Second, 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 room for misspecification (see the critique in Chari, Kehoe, and McGrattan (2009)). Third, IRF-matching additionally sidesteps weak identification concerns, as raised by Fernández-Villaverde, Rubio-Ramírez, and Schorfheide (2016).

The parameter estimates reveal that the initial increase in debt is repaid very slowly, and mainly by a decrease in government spending. Moreover, fiscal policy reacts strongly countercyclically to output deviations using tax rates. 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 the “Main Business-cycle shock” by Angeletos, Collard, and Dellas (2020), a general aggregate demand shock, the fiscal responses in the VAR model as well as the parameter estimates in the HANK model are remarkably similar. This is further evidence that the direct effect of higher interest rates does not trigger a large reaction by the government, but the macroeconomic fluctuations induced by the monetary shock do, eliciting almost the same fiscal policy reaction as a more general demand shock.

²For empirical evidence on indirect effects outweighing direct effects in monetary policy transmission, see Holm, Paul, and Tischbirek (2021), Ampudia et al. (2018), and Slacalek, Tristani, and Violante (2020).

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

Finally, the model is used as a laboratory to quantify the fiscal channel of monetary policy. In the absence of countercyclical tax policy, the tax rate does not decline after an interest rate increase. As a consequence, output drops by roughly one-third more than it would under the estimated fiscal policy response. Furthermore, the result that the monetary shock is counteracted by a stabilization motive of the fiscal authority resonates with the analogous case with reversed roles, 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 (2020)). 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). In the same vein, 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 finance higher rollover costs as well as cope with lower tax revenues to stabilize 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 several strands in the literature. By studying a type of monetary-fiscal interaction, it naturally connects to the literature studying “active” and “passive” monetary and fiscal policies, as per Leeper (1991). 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), Leeper, Traum, and Walker (2017)). Therefore, my paper focuses on an active monetary regime, which means that the central bank stabilizes inflation and fiscal policy passively balances the government budget constraint.⁴

There is an emerging literature on the fiscal role in the monetary transmission mechanism: Kaplan, Moll, and Violante (2018), Alves et al. (2020), and Bellifemine, Couturier, and Jamilov (2024) focus on interest rate costs as a key determinant of the effects of monetary policy. Auclert, Rognlie, and Straub (2020), however, argues in a model with long-term debt that the potency of such a fiscal channel is much reduced. In other work, Andreolli (2021) presents evidence that the effects of monetary policy in the U.S. may be state-dependent on the government debt maturity structure. Campos et al. (2024) argue that permanent changes in the stock of public debt affect the natural interest rate, thereby impinging on how monetary policy should be set. Relative to these papers, I allow for a general, flexible role played by fiscal policy that goes much beyond single mechanisms, such as interest rate payments. Additionally, none of the aforementioned papers try to empirically discipline the fiscal reaction in the monetary transmission mechanism.

⁴Other work has considered the possibility that fiscal policy has become active at the Zero Lower Bound (ZLB) period of the 2010s (Bianchi and Melosi, 2017), however, my results are robust to the exclusion of the ZLB episode, see section 3.3.

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, whereas Bouscasse and Hong (2023) study more generally fiscal responses using the Romer and Romer (2004) proxy series, and find the government “does not react”. However, the Romer and Romer (2004) instrument has been shown to fail exogeneity in a number of papers, therefore likely confounding exogenous and systematic monetary policy (see, among others, Aruoba and Drechsel (2023), Caldara and Herbst (2019), Miranda-Agrippino and Ricco (2021, 2023)). Breitenlechner, Geiger, and Klein (2024) study the responses of fiscal variables using high-frequency identification, but similarly to Bouscasse and Hong (2023) do not distinguish between endogenous adjustments and fiscal policy action and focus on the implications of the fiscal response for the output-inflation tradeoff for monetary policy. In addition, they argue that the transfer response is of main importance for their analysis, which I find to be small. Generally, in contrast to my analysis, both of these papers cannot characterize systematic fiscal policy rules, but apply VAR-counterfactuals by McKay and Wolf (2023) to study monetary transmission. Relative to specifying a theoretical model, the VAR-counterfactual is a complementary method that relies crucially on the joint identification of several (news-) shocks and therefore invertibility to evaluate only an approximation to the desired counterfactual (cf., Fernández-Villaverde et al. (2007)). Hence, Caravello, McKay, and Wolf (2024) suggest to supplement the McKay and Wolf (2023) approach with additional news shocks derived from estimated micro-founded models for an exact evaluation.

Finally, this paper is additionally connected to the literature on studying or estimating systematic fiscal policy rules. 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 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. An alternative route is taken by Caldara and Kamps (2017) who show how to recover estimates of feedback parameters of fiscal instruments to economic conditions from a structural VAR model. Utilizing technology shocks, the implications for the systematic tax and government spending responses to output are in line with my results, but they do not estimate coefficients for the responses to government debt. Corsetti, Meier, and Müller (2012) focus on the systematic conduct of government spending, providing evidence (using government spending shocks) that higher debt levels are eventually brought down by

below-trend government spending, which is in line with my results. Therefore, my contribution to this literature is to bring new evidence on the impulse responses of a full set of fiscal variables to bear on the estimation of richly parameterized fiscal 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. Finally, section 6 discusses the estimated fiscal policy rules and the quantification of the fiscal channel. Section 7 concludes.

2 A general model of both monetary and fiscal policy

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

$$\mathbf{x}_t = \mathbf{A}E_t[\mathbf{x}_{t+1}] + \mathbf{B}\boldsymbol{\varepsilon}_t \quad (1)$$

$$r_t = \phi_\pi \pi_t + \phi_Y Y_t + \varepsilon_t^R, \quad (2)$$

where \mathbf{x}_t denotes the vector of endogenous variables, including at least output and inflation $(Y_t, \pi_t)'$, and $\boldsymbol{\varepsilon}_t$ is a vector of exogenous stochastic processes. Equation (1) is a log-linearized, rational expectations vector-difference equation that describes a stereotypical 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, 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 modelling the fiscal block of the model explicitly.⁵ Nonetheless, even this assumption implies a very particular response by fiscal policy, and Caramp and Silva (2023) has recently shown that this fiscal adjustment via transfers creates a wealth effect that substantially shapes the adjustment in consumption after a monetary policy shock in the standard three-equation RANK model. 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

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

analysis of monetary policy not only crucially depends on assumptions for fiscal policy rules, as Kaplan, Moll, and Violante (2018) show, 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, government spending G_t , and tax rates τ_t :

$$\tau_t = \gamma_Y^\tau Y_t + \gamma_\pi^\tau \pi_t + \gamma_B^\tau B_t \quad (3)$$

$$G_t = \gamma_Y^G Y_t + \gamma_\pi^G \pi_t + \gamma_B^G B_t \quad (4)$$

The inclusion of economic conditions in the form of output Y_t and inflation π_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 $\gamma_Y^\tau = \gamma_\pi^\tau = \gamma_Y^G = \gamma_\pi^G = 0$ and either $\gamma_B^\tau > 0, \gamma_B^G = 0$ or vice versa. In order to obtain a complete 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 move 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 macro moments in the data, which will be carried out in the next section.⁶ 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 - by construction - strong instrument 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 theoretical model of monetary policy transmission. The parameters governing the dynamics of the model (1) - (2)

⁶Caldara and Kamps (2017) go an alternative route and recover the fiscal policy parameters directly from the equation embedded in the VAR, which are not conditional on monetary policy, however. In section 6 I compare my results to theirs.

as well as the description of fiscal policy (3) - (4) can then be estimated by impulse response matching (Christiano, Eichenbaum, and Evans, 2005). In the analysis of fiscal policy as a monetary transmission channel, it is crucial that the model captures the effects of fiscal policy instruments well. Therefore, the non-policy block of the model will be described by a Heterogeneous Agent New Keynesian model with rich household heterogeneity and a two-asset structure. This modern workhorse model of business cycles has been documented by Auclert, Rognlie, and Straub (2018) and Kaplan and Violante (2022) to achieve both a fiscal policy transmission in line with the empirical literature as well as a realistic income and wealth distribution.

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.

3.1 Time series framework

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

$$\mathbf{y}_t = \sum_{l=0}^{\infty} \Theta_l \varepsilon_{t-l}, \quad (5)$$

where ε_t is the unobserved white noise vector of exogenous fundamental shocks $\varepsilon_t \sim \text{WN}(\mathbf{0}, \mathbf{I}_{n_\varepsilon})$. The coefficient matrices Θ_l , assumed to have full rank, 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:

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

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 Bayesian mixed-frequency 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.

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 $\tilde{\mathbf{y}}_t = (z_t, y_{1,t}, \dots, y_{n,t})'$, 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, structural impulse response functions Θ_t can still be consistently estimated even if the monetary policy shock is noninvertible (i.e., if $\varepsilon_{1,t} \notin \text{span}(\{\tilde{\mathbf{y}}_\tau\}_{-\infty < \tau < t})$). Plagborg-Møller and Wolf (2022) and Forni, Gambetti, and Ricco (2022) present evidence that the invertibility assumption for high-frequency identification of monetary policy as in Gertler and Karadi (2015) 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.⁷ 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, identification of monetary policy shocks using high-frequency financial markets instruments is the current gold standard in the literature (e.g., Wolf (2020)), by relying on relatively weak identifying restrictions and external “as-if” randomness. The leading alternative to high-frequency identification is to isolate exogenous movements in the federal funds rate by controlling for the Fed information set, pioneered by Romer and Romer (2004). However, as highlighted by Ramey (2016), this approach is plagued by the price puzzle and is confined to samples that stop in 2008. Aruoba and Drechsel (2023) recently improved on this narrative method, but they rely on additional sign-restrictions to circumvent the price puzzle.

Fourth, a relatively short sample period in combination with a high-dimensional number of endogenous variables warrants the incorporation of prior information to achieve shrinkage,

⁷In this pursuit, Buda et al. (2023) and Jacobson, Matthes, and Walker (2022) use daily macroeconomic data. Jacobson, Matthes, and Walker (2022) show that even at monthly frequency, time aggregation can bias estimates of monetary policy transmission.

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, several fiscal variables are added. At least the two main instruments of fiscal policy, government spending and taxes, need to feature in the model, but government debt is an important variables as well. Spending and taxes endogenously react to debt, so not allowing for this relationship in the empirical setup likely leads to misspecification (cf. Mertens and Ravn (2013)). Therefore, including the monetary policy proxy, the minimum number of variables in the VAR will be eight. In addition, and unrelated to the dimensionality of the model, Li, Plagborg-Møller, and Wolf (2022) recommend the usage of a VAR with shrinkage when estimating effects of structural macroeconomic shocks based on the bias-variance tradeoff.

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, 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 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.

Identification is achieved by use of high-frequency changes in financial market contracts around FOMC monetary policy announcements as an instrument for policy shocks, in the spirit of Gertler and Karadi (2015). In a large subsequent literature this identification scheme emerged as the leading strategy of monetary policy shock identification, with Bauer and Swanson (2023a) as the most recent advancement. They challenge the previous literature which suggested that contamination of the high-frequency surprises result 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 (2023b) reveals 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).

The reduced-form model to be estimated is the MF-BVAR model of Schorfheide and Song

(2015). Because of the high-dimensional problem and relatively short sample size dictated by the availability of the instrument, a standard Minnesota-type prior is used. The prior is implemented using dummy variables, following Sims and Zha (1998).⁸ The proxy by Bauer and Swanson (2023a) 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 (note that the prior mean on the first autoregressive lag of the proxy is set to 0 instead of 1). The MF-BVAR is estimated with 12 lags and a constant on the sample April 1988 to December 2019 (based on the availability of the proxy). 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 (2023a) 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.¹¹ The average effective tax rate falls, reaching a trough after about 20 months. The tax rate, based on the National Income and Product Account (NIPA) tax base and revenues, captures tax income from all taxes in the United States.¹² Therefore, it encompasses all possible margins of the tax schedule that could be adjusted. In summary, Figure 1 suggests that tax policy becomes

⁸The 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 one, 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 a very similar application.

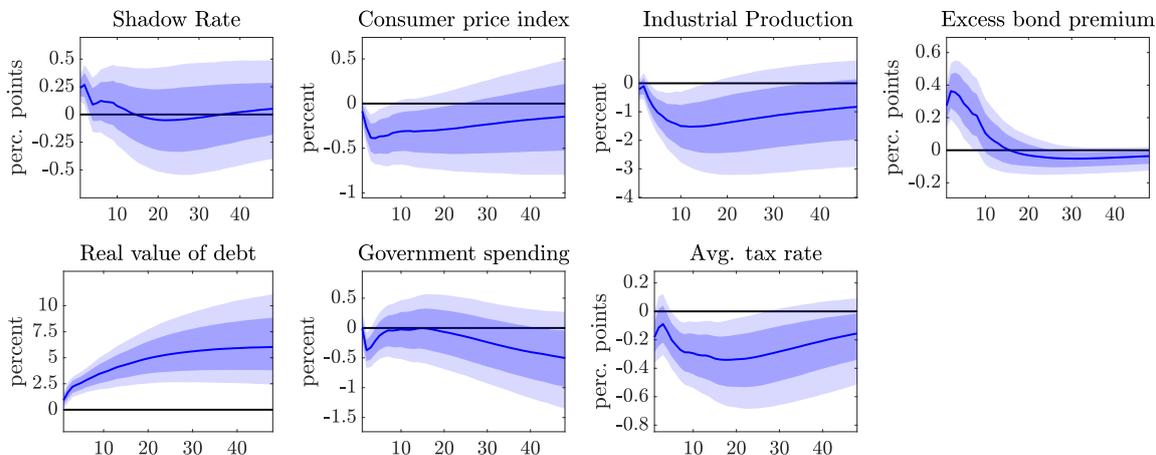
⁹The required number of iterations in all specifications of the MF-BVAR exceeds the minimum number as suggested by the Raftery and Lewis (1992) diagnostic.

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

¹¹Figure B.1 in the appendix presents results for government consumption and investment separately, both at the federal and state level. They show that it is mostly investment that is responsible for the fall in spending, particularly at the state level.

¹²For a detailed description of the construction of all data series, see appendix A.1.

Figure 1: MF-BVAR: Baseline responses to a monetary policy shock

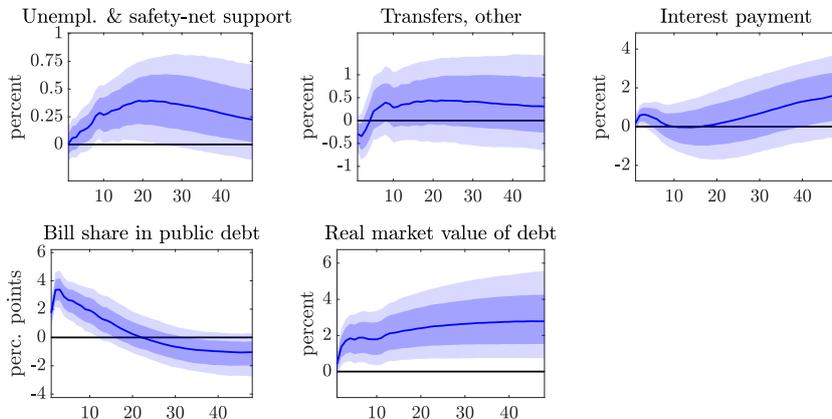


Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

expansionary after a contractionary monetary shock, alongside an increase in the stock of debt and a gradual decline in government spending.

Next to government debt, spending, and taxation, a key instrument of fiscal policy is transfers. To keep the dimensionality of the VAR manageable, further fiscal variables are added to the baseline model in Figure 1 one by one. Figure 2 shows Unemployment and other safety-net support benefits, all other government transfers, federal interest payments, and the real market value of government debt. After the contractionary shock, unemployment benefit payments rise moderately to a peak after 20 months. This is in line with a commensurate increase in the unemployment rate (not shown). 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 small: Unemployment and other safety-net support measures only average 2.6% of GDP over the sample period - hence, a 0.4% peak increase is inconsequential economically. 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 share of long-term debt, interest rate payments by the federal government increase only very slowly and with high posterior probability after four years. In fact, this response suggests, consistent with the transitory increase in the Shadow Rate that reverted back close to zero after roughly a quarter, that the monetary policy shock does not materially increase the average interest rate on newly issued debt, but increases total interest payments mechanically since the stock of

Figure 2: MF-BVAR: Further 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.

debt increases.¹³ 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 cost, a temporary shift in the composition of debt contributes to low interest payments on the debt. Finally, not only the amount of debt outstanding increases, as shown in Figure 1, but also the market value, though by less. This measure of debt corresponds more closely to the debt definition in models with one-period debt and will therefore serve as an input in the estimation of the HANK model.

Appendix B.1 contains results to robustness exercises concerning the monthly-quarterly model presented so far. Figure B.3 shows that the results are robust to using the 1-year Treasury yield instead of the Shadow Rate, and Figures B.4 and B.5 show that tax revenues, as well as cyclically adjusted tax revenues, fall very similarly to the average tax rate used in the baseline (see also the discussion at the end of the next section 3.4). Furthermore, the results so far are robust to excluding the Zero Lower Bound (ZLB) period, which Swanson and Williams (2014) argue started to constrain monetary policy beginning in 2011. Therefore, Figure B.6 shows the baseline model for the period 1988m3 – 2010m12.

¹³Consistent with this interpretation, the aggregate demand shock identified in section 3.5 leads to a very similar shape of interest payments on government debt. Although the interest rate declines in response to the demand shock, interest payments fail to decline but instead increase after several years, consistent with a rising debt level, see Figures 4 and B.9.

3.4 Mechanical fiscal adjustments or policy action?

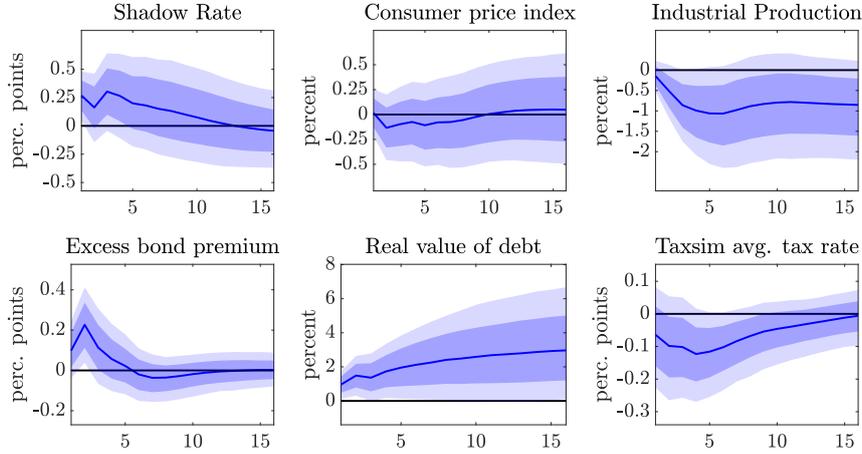
The fiscal policy response to the contractionary shock hitting the economy is characterized by a reduction in the average tax rate and by increased transfers in the form of unemployment and safety-net transfers. Are the expansionary fiscal responses a mechanical reaction to economic conditions, i.e., to lower tax income? Or is U.S. fiscal policy systematically reacting to the shock by cutting the average tax rate? Disentangling tax policy action from non-legislated changes in the tax burden is challenging because the effective average tax rate may change automatically because of variation in the level of income, inflation, or changes in stock prices, among other reasons. However, all of these non-policy changes in the tax rate result from a change in the income distribution. Consequently, a calculation of the average tax rate based on a constant income distribution over time reflects changes in the tax schedule only. Such a measure is available in annual frequency by the NBER TAXSIM program.¹⁴ 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. 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. Importantly, the TAXSIM measure takes into account not only changes in the marginal tax rates, but also changes to tax deduction and tax credit, adding to variation in the total tax burden (see Figure A.2 for changes in marginal tax rates for different income levels).

Figure 3 presents the impulse responses to a monetary policy shock in a quarterly-annual model. Compared to Figure 1, a loss of precision in the estimates is clearly visible by moving to a lower frequency. The consumer price 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 spending is dropped and only eight lags are included such that the annual variable may still depend on its own lag.

The TAXSIM measure 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. Yet, the impulse response function of the TAXSIM tax rate assigns some non-trivial probability mass to the tax change occurring quite quickly, even in the same quarter. Given institutional constraints this is unlikely, but here results directly from the implicit assumption in unrestricted VAR models that endogenous variables can adjust contemporaneously. This simplification implicit in general VAR models

¹⁴For the TAXSIM program, see Feenberg and Coutts (1993) and <https://www.nber.org/taxsim>.

Figure 3: MF-BVAR: quarterly - annual model for the 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.

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.7 and B.8 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, as well as fit the institutional constraints of U.S. legislation that may need up to a year to change the tax code.

A 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). By purging federal tax revenues from fluctuations due to economic conditions, in principle, this measure should show no decline in response to a monetary shock if lower tax revenues due to falling incomes are fully corrected for and the tax rates stay unchanged. However, in appendix B.1, Figure B.5 it is shown that this measure falls as well. The difference in the impulse response to that of unadjusted tax revenues (Figure B.4) suggests that about half of the drop in tax revenues is mechanically due to falling incomes, and the other half is due to countercyclical tax policy. Finally, Figure

¹⁵Romer and Romer (2010) analyze post-WWII tax changes until 2007 and document that tax changes can occur in any given quarter. Hence, imposing a constant tax rate in every calendar year is quite restrictive.

B.2 in the appendix shows that the marginal tax rate is unchanged after a monetary policy shock. Hence, progressiveness of taxation stays unaltered.

3.5 The fiscal response to a general demand shock

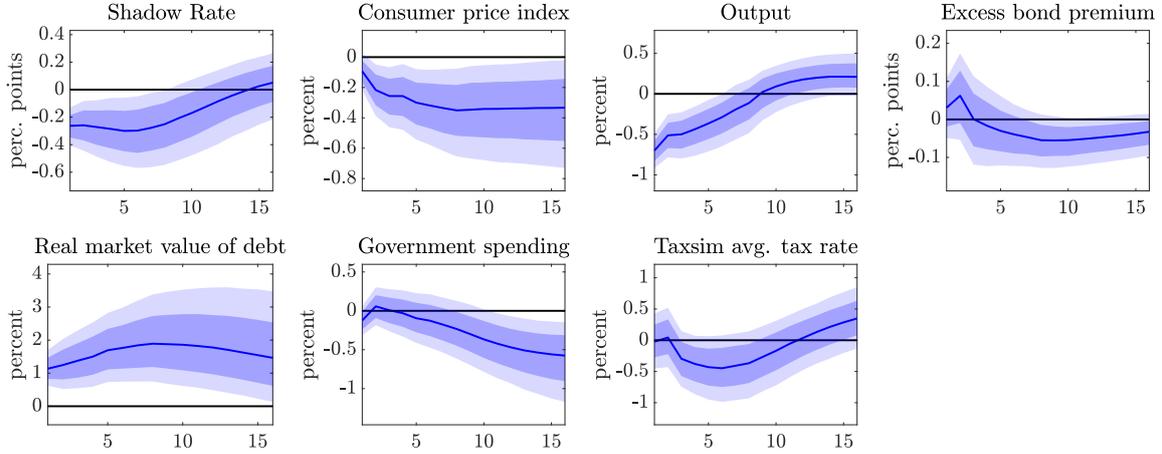
The empirical exercise presented so far aimed at estimating the endogenous, or systematic, fiscal response to monetary policy shocks. In the subsequent analysis, the estimated impulse response functions serve as the empirical moments to identify the parameters of the structural model (1) - (4). Since the monetary policy shock induces dynamics in all the variables that fiscal policy may conceivably react to systematically, such as output, government debt, the price level, or interest rates, the impulse responses identify parameters in the fiscal rules, conditional on a monetary policy shock. To shed light on the generality of the fiscal policy rules identified with the empirical strategy in this paper I additionally consider the demand shock by Angeletos, Collard, and Dellas (2020) as a second source of identifying variation. This serves two purposes. First, the effects to the more general demand shock can provide a first answer to whether the fiscal responses documented so far are to the interest rate *per se*, or to the macroeconomic consequences thereof. Implicitly, the impulse responses can tell us whether the fiscal response is special to monetary policy, or more generally a reaction to demand disturbances. Second, the recent empirical literature finds that the role of monetary policy as a source of business cycle fluctuations is modest (e.g., Caldara and Herbst (2019), Plagborg-Møller and Wolf (2022)), therefore the monetary policy induced variation in macro aggregates might provide weak identification restrictions. Angeletos, Collard, and Dellas (2020) argue that the “Main Business Cycle Shock” (MBC) computed in their study accounts for the largest share of variation by a single source in typical macroeconomic time series such as output, consumption, hours worked, investment, and more. Therefore, the impulse responses to their shock will serve as strong moments for identification by construction.

The shock is available in quarterly frequency, therefore the MF-BVAR employed is the quarterly-annual specification of section 3.4. The sample is restricted to the post-Volcker disinflation period, consistent with the empirical analysis so far and the calibration of the microfounded model in section 4. Therefore, in line with Bernanke and Mihov (1998) who identify February 1984 as the start of the post-Volcker disinflation regime, the sample runs from 1984Q1 to 2017Q4, until which the MBC shock is available.

Instead of the real value of debt outstanding and industrial production, Figure 4 shows the responses of (detrended) output (Hamilton (2018) filtered GDP, see the data appendix) and the real market value of debt, since these are the variables that are going to be matched to the micro-founded model in section 6.¹⁶ The MBC shock depresses output on impact, as is the case for GDP in Angeletos, Collard, and Dellas (2020); leads to the price level falling, and

¹⁶The responses of industrial production and the par value of debt are very similar.

Figure 4: MF-BVAR, quarterly - annual model: 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.

a mild increase in the excess bond premium. The shadow rate falls immediately, consistent with accommodative monetary policy. Finally, the fiscal variables respond very similarly as to the monetary policy shock: debt increases, government spending falls with a long delay, and the tax rate declines after about a year. Figure B.9 in the appendix shows that the transfer response is very similar as well. Hence, the systematic fiscal response to this very general demand shock are basically the same as to the monetary policy shock. This points to, first, the generality of the fiscal response to demand-side disturbances, and second, that the expansionary tax rate policy action is unrelated to the interest rate change itself, but rather it’s implications for the macroeconomy.

3.6 Discussion of empirical results

In summary, a monetary policy shock induces debt-financed countercyclical tax 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 not only holds for a monetary policy shock, but also for a more general aggregate demand shock. Two conclusions can be drawn at this point.

First, these results suggest that systematic fiscal policy counteracts the monetary shock. Since it is well known that fiscal stimulus depends on the systematic monetary policy response (see, e.g., Christiano, Eichenbaum, and Rebelo (2011), Woodford (2011), Cloyne, Jordà, and

Taylor (2020), Hack, Istrefi, and Meier (2023)) this is the analogous case in reverse. This interpretation is in line with the notion of a business-cycle stabilization motive for fiscal policy, as is well documented, e.g., in the statements of tax legislation itself, where economic conditions are cited as the reason for tax changes (Romer and Romer, 2010). Second, the muted response of interest payments on government debt is evidence against a strong fiscal channel of monetary policy that works via interest rate costs.

What we can learn about a fiscal channel of monetary policy only from the 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. Does the fiscal authority react to interest rates *per se*, or only to economic conditions? Does it react to output losses, in line with a stabilization of business cycles motive, or rather to inflation? Which fiscal instrument is adjusted to pay back the higher debt level, and at what pace? To answer these questions, the policy rules governing 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 canonical two-asset HANK 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 the 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 for such a model a rich description of the transmission of monetary and fiscal policy. Heterogeneous Agent New Keynesian (HANK) models meet these requirements. The HANK model described here is deliberately taken “off the shelf” and follows Bayer, Born, and Luetticke (2023, 2024) closely. The model 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 described below. 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 (real) 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 taxed at rate τ_t .

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

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

where x_{it} is the composite demand of household i for goods consumption c_{it} and leisure $(1-n_{it})$.¹⁷ ξ denotes the constant relative risk aversion parameter and γ 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 μ 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, Diaz-Giménez, and Rios-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 process is therefore described as

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

¹⁷Goods consumption of household i in period t is the usual Dixit-Stiglitz aggregator over j differentiated goods:

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

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

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

Given their net labor income $(1 - \tau_t)w_t h_{it} n_{it}$, 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 $R(b_{it}, R_t^b)$, which depends on the central bank's interest rate R_t^b , which is set one period before, and the bond holdings of the household. It is possible to borrow at the wasted intermediation cost \bar{R} , therefore

$$R(b_{it}, R_t^b) = \begin{cases} A_t R_t^b & \text{if } b_{it} \geq \underline{B}, \\ A_t R_t^b + \bar{R} & \text{if } b_{it} < \underline{B}. \end{cases} \quad (11)$$

A_t is included as a stand-in for a typical demand shock in the spirit of a risk-premium shock as in Bayer, Born, and Luetticke (2024) or a discount-factor shock and evolves according to a log-AR(1) process with persistence ρ_A . 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:

$$\begin{aligned} c_{it} + b_{it} + q_t k_{it} &= b_{it} \frac{R(b_{it}, R_t^b)}{\pi_t} + (q_t + r_t)k_{it} + (1 - \tau_t)(h_{it}w_t N_t + \mathcal{I}_{h_{it} \neq 0} \Pi_t^u + \mathcal{I}_{h_{it} = 0} \Pi_t^F), \\ b_{it} &\geq \underline{B}, \\ k_{it+1} &\geq 0, \end{aligned} \quad (12)$$

where q_t is the price of capital and r_t its dividend net of depreciation, $\pi_t = \frac{P_t - P_{t-1}}{P_{t-1}}$ realized inflation, and \underline{B} an exogenous borrowing limit. The household's optimization problem can now be stated as follows. Let $\Theta_t(b, k, h)$ be the distribution of households over the 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 aggregate 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 (12), 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

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

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.¹⁸

¹⁸Due 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 .

4.2.1 Unions and labor packers

There exists a unit mass of unions indexed by j , who buy labor services from households (n_{jt}) 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

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

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

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

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:

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

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):

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

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 $\kappa_w = \frac{(1-\lambda_w)(1-\lambda_w\beta)}{\lambda_w}$.

4.2.2 Intermediate Goods Producers

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

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

featuring variable capital utilization u_t , to produce the homogeneous output good Y_t .¹⁹ They charge mc_t to the final goods producers, hence the standard firm profit maximization problem reads $\max_{\{K, N, u\}} mc_t Y_t - w_t^F N_t - [r_t + q_t \delta(u_t)] K_t$ 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:

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

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

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

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 $y_{jt} = \left(\frac{p_{jt}}{\bar{P}_t} \right)^{-\eta} Y_t$ for all j . Firm's managers maximize future expected discounted real profits:

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

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:

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

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 $\kappa_Y = \frac{(1-\lambda_Y)(1-\lambda_Y\beta)}{\lambda_Y}$.

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 :

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

¹⁹A 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 increasing and convex, and without loss of generality, steady state utilization is normalized to 1.

The optimality condition is given by

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

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

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

4.3 Policy rules

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.

$$\frac{R_{t+1}^b}{\bar{R}^b} = \left(\frac{R_{b,t}}{\bar{R}_b} \right)^{\rho_R} \left(\frac{\pi_t}{\bar{\pi}} \right)^{(1-\rho_R)\theta_\pi} \left(\frac{Y_t}{\bar{Y}_{t-1}} \right)^{(1-\rho_R)\theta_Y} \varepsilon_t^R \quad (28)$$

The tax rate and government spending processes are non-linear versions of equations (3) and (4), each additionally including an autoregressive lag component:

$$\frac{\tau_t}{\bar{\tau}} = \left(\frac{\tau_{t-1}}{\bar{\tau}} \right)^{\rho_\tau} \left(\frac{Y_t}{\bar{Y}} \right)^{(1-\rho_\tau)\gamma_Y^\tau} \left(\frac{B_t}{\bar{B}} \right)^{(1-\rho_\tau)\gamma_B^\tau} \quad (29)$$

$$\frac{G_t}{\bar{G}} = \left(\frac{G_{t-1}}{\bar{G}} \right)^{\rho_G} \left(\frac{Y_t}{\bar{Y}} \right)^{(1-\rho_G)\gamma_Y^G} \left(\frac{B_t}{\bar{B}} \right)^{(1-\rho_G)\gamma_B^G} \quad (30)$$

$$G_t = B_{t+1} + T_t - R_t^b / \pi_t B_t \quad (31)$$

Spending and taxes are allowed to respond to economic conditions and debt. The rules are kept deliberately standard and flexible, and Equation (31) is the usual government budget constraint.

4.4 Market clearing, Equilibrium, and Solution

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

$$B_{t+1} = \int \lambda b_{a,t}^*(b, k, h) + (1 - \lambda) b_{n,t}^*(b, k, h) d\Theta_t(b, k, h), \quad (32)$$

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 $(R_t^b, r_t, q_t, \Pi_t^F, \Pi_t^U, w_t, \pi_t)$. Similarly for the capital market, the aggregate supply of capital rented out by households has to equal capital demand from firms

$$K_{t+1} = \int \lambda k_t^*(b, k, h) + (1 - \lambda)k d\Theta_t(b, k, h), \quad (33)$$

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 Walra’s law. The definition of the sequential competitive equilibrium is standard and relegated to appendix C.1.

Finally, 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 easily feasible, to which I turn to next.

5 Model calibration and estimation

In line with much of the impulse response matching literature, the model is estimated using a two-step approach. First, parameters influencing 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

In line with much of the HANK literature, 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) identifies February 1984 as the end of the Volcker disinflation, therefore the calibration sample is 1984 – 2019.²⁰ Table 1 summarizes the parameters of the

²⁰For the data sources and definitions used in the calibration, see Appendix A.2.

model that are calculated either directly from long-run time series averages to represent steady state ratios, or internally calibrated to match such targets. Specifically, 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, $\frac{B}{K} = 0.14$, (iii) the fraction of hand to mouth households of 31% (Kaplan, Violante, and Weidner, 2014), and (iv) the wealth Gini of 0.83. 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 borrowing limit and the portfolio adjustment probability are set to match the share of hand-to-mouth households and the average liquidity (publicly 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.

5.2 Second step: Estimation

The IRF matching procedure (and exposition) follows Christiano, Trabandt, and Walentin (2010). \mathbf{y}_t contains the variables in the VAR (of dimension $n \times 1$) and $\hat{\boldsymbol{\psi}}$ collects the empirical IRFs, stacked, such that $\hat{\boldsymbol{\psi}}$ has dimension ($n \times \text{IRF-horizon} \times 1$). 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 (since debt in the model is one-period debt), real government spending, and the TAXSIM tax rate. Since industrial production only represents a small fraction of total production, it is replaced by a measure of (detrended) output, the cyclical component of real per-capita GDP computed using the Hamilton (2018) filter, which is more in line with the output concept in the model, Y_t . In this application, the parameter vector is given by²¹

$$\boldsymbol{\theta} = (\delta_2, \phi, \kappa_Y, \kappa_w, \rho_R, \sigma_R, \theta_\pi, \theta_Y, \rho_G, \gamma_B^G, \gamma_Y^G, \rho_\tau, \gamma_B^\tau, \gamma_Y^\tau)'. \quad (34)$$

The asymptotic variance of the normally distributed $\hat{\boldsymbol{\psi}}$ is $V(\boldsymbol{\theta}_0, T)$ and 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 empirical model is in monthly frequency but the theoretical model in quarterly frequency, the empirical impulse responses are averaged to

²¹More 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.

Table 1: Calibrated parameters in the HANK model

Parameter	Value	Description	Target or source
<i>Households</i>			
ξ	2.0	Relative risk aversion	Standard value
β	0.98	Subjective discount factor	$K/Y = 2.83$
γ	2.0	Inverse of Frisch elasticity	Chetty et al. (2011)
λ	6.40%	Portfolio adjustment probability	$B/K = 0.14$
\underline{B}	0.0	Borrowing constraint	Share of hand-to-mouth = 31%
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)
ζ	0.05%	Transition prob. from W. to E.	Wealth Gini = 0.83
<i>Firms</i>			
α	0.61	Share of labor	Penn World Table 10.01
δ_0	1.9%	Depreciation rate	7.8% p.a.
$\bar{\eta}$	7	Elasticity of substitution	Price markup 15%
$\bar{\zeta}$	7	Elasticity of substitution	Wage markup 15%
<i>Government</i>			
$\bar{\tau}$	0.28	Tax rate level	$G/Y = 19\%$
\bar{R}_b	1.00	(Gross) Nominal rate	Real MZM own rate ≈ 0

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 means on the Philips curve parameters κ_Y, κ_w reflect the belief of pricing contracts having an average length of one year. Turning to the parameters in the Taylor rule, estimation results for the inflation coefficient repeatedly find a value about 2: Clarida, Gali, and Gertler (2000), Smets and Wouters (2007), Bayer, Born, and Luetticke (2024), and Carvalho, Nechio, and Tristao (2021). The standard deviations are relatively tight. The estimation on a monetary policy shock is not well suited to identify parameters in the Taylor rule; however for the estimation on the aggregate demand shock the parameters of the Taylor rule are of interest. In the empirical model of section 3, the Minnesota prior imposes persistent behavior of the time series, therefore, a relatively high degree of interest rate smoothing is appropriate. 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,

Table 2: Prior and posterior distributions of estimated parameters

Parameter	Prior			Posterior	
	Distribution	Mean	Std. dev.	HANK	RANK
<i>Frictions</i>					
δ_s	Gamma	5.00	2.00	4.02 [1.57, 7.33]	4.20 [1.60, 7.88]
ϕ	Gamma	4.00	2.00	4.7 [2.14, 7.98]	3.82 [1.49, 7.20]
κ_Y	Gamma	0.1	0.02	0.095 [0.068, 0.128]	0.087 [0.057, 0.122]
κ_w	Gamma	0.1	0.02	0.089 [0.061, 0.121]	0.093 [0.063, 0.126]
<i>Taylor rule</i>					
ρ_R	Beta	0.85	0.1	0.98 [0.97, 0.99]	0.93 [0.88, 0.96]
σ_R	Inv. Gam.	0.05	0.02	0.078 [0.045, 0.118]	0.074 [0.04, 0.11]
θ_π	Normal	2.0	0.2	1.96 [1.63, 2.30]	1.93 [1.60, 2.25]
θ_Y	Normal	0.125	0.05	0.116 [-0.2, 0.43]	0.125 [-0.20, 0.45]
<i>Fiscal rules</i>					
ρ_G	Beta	0.5	0.2	0.84 [0.55, 0.96]	0.60 [0.23, 0.93]
$-\gamma_B^G$	Gamma	0.5	0.25	0.36 [0.19, 0.61]	0.10 [0.05, 0.17]
γ_Y^G	Normal	0.0	1.0	-0.07 [-0.99, 0.93]	0.68 [-0.75, 2.01]
γ_π^G	Normal	0.0	1.0	-0.22 [-1.58, 1.13]	0.03 [-1.42, 1.39]
ρ_τ	Beta	0.5	0.2	0.71 [0.34, 0.91]	0.81 [0.50, 0.96]
γ_B^τ	Gamma	0.5	0.25	0.14 [0.05, 0.27]	0.06 [0.02, 0.13]
γ_Y^τ	Normal	0.0	1.0	1.54 [0.50, 2.65]	1.55 [0.35, 2.80]
γ_π^τ	Normal	0.0	1.0	1.03 [-0.55, 2.6]	0.54 [-1.1, 2.14]

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

and Luetticke (2023), with standard normal priors on the output and inflation coefficients. After mode-finding, credible sets are based on a standard random walk Metropolis-Hastings algorithm.²²

²²For more details as well as diagnostic checks on convergence, see appendix D.2.

6 Estimated fiscal rules and the fiscal channel of monetary policy

This section presents the quantitative results of the estimated HANK model and subsequently an analysis of the implications of the fiscal channel for the transmission of monetary policy. First, I show that the estimated HANK model matches both the target evidence well, and furthermore lines up with empirical evidence on key untargeted moments of the data for fiscal policy, unlike its corresponding RANK counterpart. The parameter estimates of the fiscal rules are shown to be robust both to the specification of fiscal rules, and to an external validity exercise estimating the model based on macro moments from the (MBC) aggregate demand shock instead of the monetary policy shock. Second, the model will be used to decompose the overall fiscal budgetary impact of monetary policy into its components for quantifying their relative magnitudes. Finally, using a series of counterfactuals, I show how the government’s business-cycle stabilization motive shapes the effects of monetary policy and how the response of the fiscal instruments to output and inflation matters.

6.1 Parameter estimates and model fit

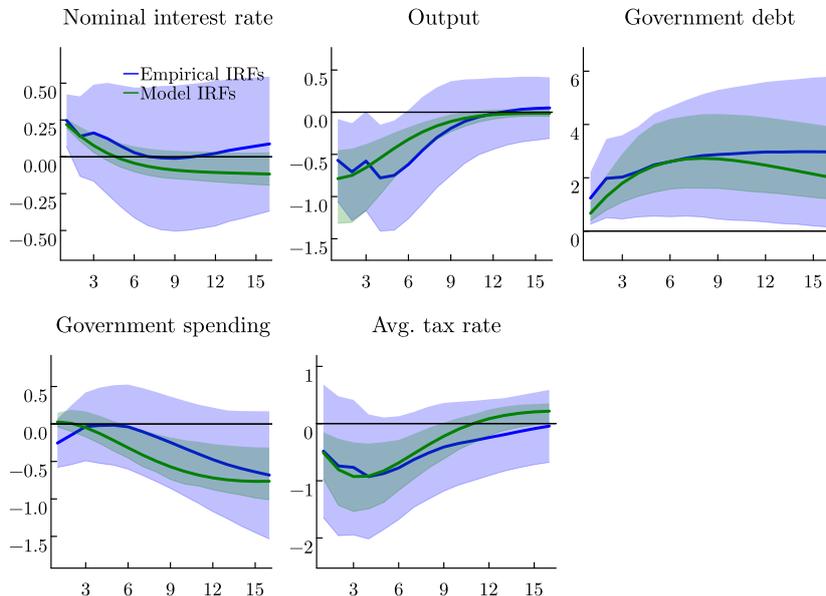
Figure 5 shows the empirical impulse responses in blue versus the model-implied impulse responses with estimated parameters at their posterior mean as well as 90% credible sets in green. Overall, the model produces a good fit to the empirical evidence, with credible sets almost always covering the empirical median impulse response. Government debt is highly persistent and the troughs in output as well as the tax rate are matched well, which is going to be important for quantifying the absence of fiscal stabilization policy. Of note is the typical difficulty of DSGE models to produce hump shapes in output endogenously, even though the impulse response of (detrended) output does not display a strong hump shape.²³

Column 5 of Table 2 presents the posterior means of the estimated parameters. In general, the friction parameters are in line with the New Keynesian DSGE literature, with relatively flat price and wage Phillips curves, in line with e.g. Hazell et al. (2022). The Taylor rule parameters are mostly close to the prior means, but the estimated model implies a strong smoothing parameter ρ_R of 0.98, exactly the same value as 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 sharper identification of 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).

Of main interest are the parameters of the fiscal policy rules. The estimated coefficients

²³To match the trough in output after 5 quarters, as in the data, Auclert, Rognlie, and Straub (2020) show that a behavioral feature will go a long way.

Figure 5: Impulse response matching of the HANK model to a monetary policy shock



Notes: Impulse response functions (IRFs) to a monetary policy shock. Model IRFs: posterior mean estimates and 90% credible sets. All variables are displayed as percent deviations from steady state.

provide an answer as to the motive behind the fiscal adjustments: does systematic fiscal policy respond to output and inflation deviations? Is government spending or income taxation responding to debt increases? The parameters governing the repayment of debt, γ_B^G and γ_B^T , 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 0.36 percent, and a 0.14 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 are often the only instrument to finance debt.²⁴ Furthermore, the pace of repayment is very slow: after the monetary shock, debt remains elevated for roughly seven years. Finally, of the two output coefficients in the fiscal policy rules, the feedback from output to tax rates stands out, being positive and large with a value of 1.54. 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 close to zero. The coefficients on inflation suggest some response to inflation, especially

²⁴See, e.g., McKay, Nakamura, and Steinsson (2016), Auclert, Rognlie, and Straub (2020), McKay and Wolf (2022). Note that the estimated debt-parameter of the tax rule is positive, so the income tax rate does increase in response to higher debt levels. However, in the short run this effect is fully dominated by the response of the tax rate to output. Indeed, in Figure B.2 in the appendix I show that the average tax rate eventually does increase, in line with the HANK model parameter estimates, but with substantial delay.

by the tax rate. However, the credible sets for both inflation coefficients cover zero and therefore a nontrivial likelihood that these are small. Their relative importance compared to the output coefficient will be explored in more detail in section 6.3. 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.

In order to compare these estimates and the fiscal channel of monetary policy in HANK versus in RANK, I estimate the corresponding RANK economy using the exact same impulse response-matching procedure and the same 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. Yet, the estimated RANK model matches the empirical evidence worse in several key aspects, as shown in Figure D.2 in the appendix: the RANK model features less persistence, does not reproduce the troughs in the tax rate and output and overall provides a poorer model fit compared to the HANK model. What is more, for the estimated model to constitute a good laboratory to study the fiscal channel of monetary policy, the model should not only fit key IRF responses well, but also match other summary moments that describe the effects of fiscal policy. To that end, Table 3 compares the sufficient statistics that describe the effects of fiscal policy in the data to those implied by the HANK and RANK models. The key statistic describing the effects of tax and government spending policy is their cumulative output multiplier.²⁵ For the estimated model, the tax multiplier - the change in output resulting from a change in the tax rate that reduces tax revenues by 1% of GDP - is 2.2, and for the government spending multiplier it is 1.6. Both estimates are in line with the ones typically found in the empirical literature surveyed by Ramey (2019). In addition, the marginal propensity to consume 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.

Next, the robustness of the fiscal policy rules is examined by, a), extending the input arguments of the fiscal policy rules, and b) by estimating the HANK model on completely different empirical evidence as an external validity check, by utilizing the aggregate demand shock evidence from section 3.5 instead. 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.1 in the appendix shows that extending the fiscal policy rules to allow for a direct reaction of the fiscal tools 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. Moreover, Table D.2 shows that the fiscal policy parameter

²⁵Ramey (2019) and Mountford and Uhlig (2009) argue that cumulative multipliers are the more robust description of the data than impact multipliers.

Table 3: Untargeted fiscal moments

Moments	HANK	RANK	Data	Data source
Cumulative tax multiplier	-2.2	-0.8	[-2.0, -3.0]	Ramey (2019)
Cumulative spending multiplier	1.6	0.9	[0.6, 2.0]	Ramey (2019)
MPC (quarterly, \$500)	0.17	0.01	0.15–0.25	Havranek and Sokolova (2020)

Notes: Cumulative government spending multiplier is computed over five years, corresponding to the empirical evidence in Ramey (2019); the tax multiplier is the peak multiplier, again as in Ramey (2019).

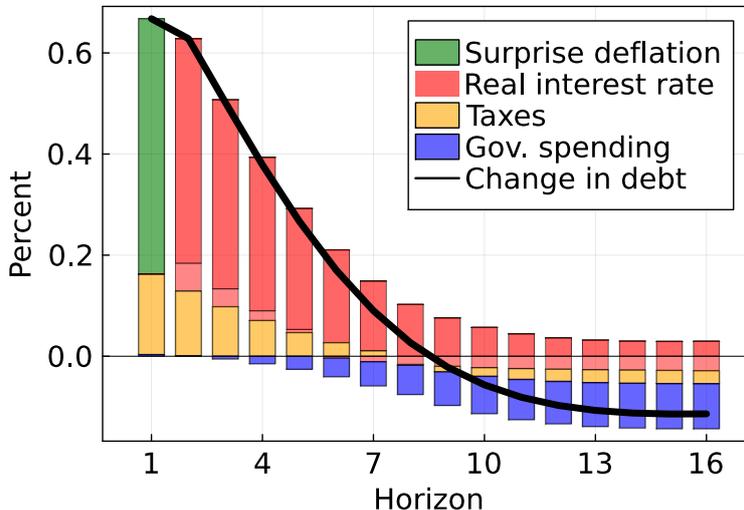
estimates from the demand shock estimation are remarkably similar to the ones reported in the baseline estimation conditional on a monetary policy shock. The Main Business-cycle Shock is constructed such that it is the source that moves the typical U.S. business-cycle most, constituting a strong instrument for exogenous variation by construction. Therefore, the strong similarity in estimates is comforting and alleviates model misspecification concerns.

Finally, the estimates in Tables 2 and D.1 are furthermore in line with recent evidence by Caldara and Kamps (2017), despite a very different identification strategy utilizing technology, oil and Romer and Romer (2004) shocks. Specifically, they estimate a strong positive output coefficient in the tax rule, alongside a coefficient close to zero on output for 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. 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.

6.2 Quantifying and decomposing monetary policy’s implications for the federal budget

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. Figure 6 shows the change in real government debt after a monetary surprise, decomposed into its drivers. While the expansionary tax policy does impact the federal budget in the form of lower tax revenues, it is the effect of the interest rate on the price level that dominates the dynamics of government debt. The higher real interest rate costs on the debt stem overwhelmingly from the revaluation of debt in real terms, not from higher nominal interest rate payments on rolled-over debt (the lighter part of

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. The lighter red bars indicate the nominal interest rate contribution. Percent changes in deviation from steady state.

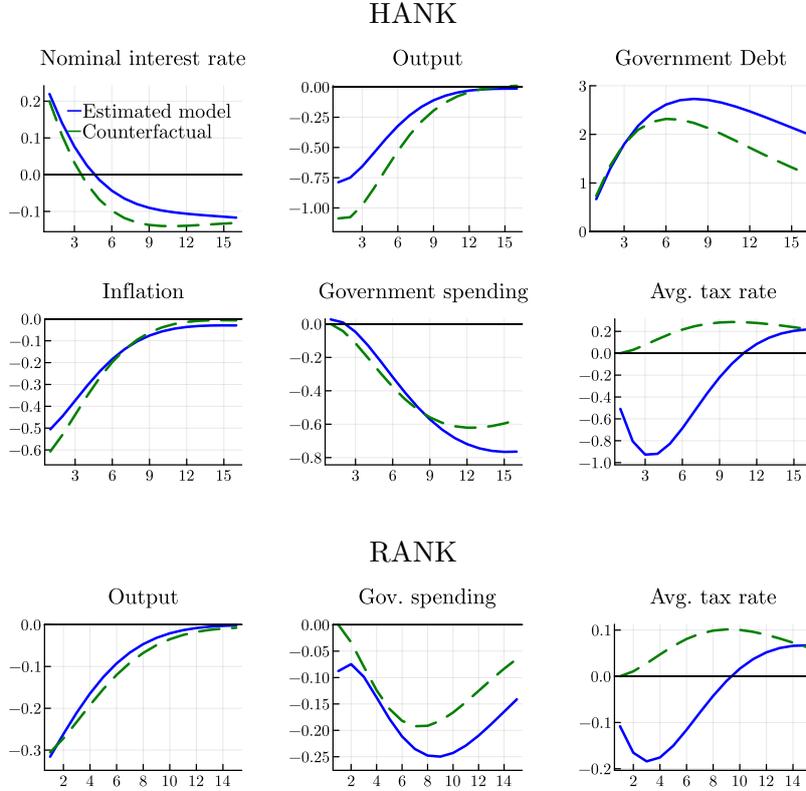
the red bars). Therefore, a model with long-term debt does not alter this strong impact of the interest rate on the debt level if the monetary consequences on inflation are unchanged. The presence of long-term debt only reduces the higher costs due to higher nominal interest rates, not to higher real interest rates. If the effects of interest rate surprises on inflation are in line with the evidence on the U.S. post-Volcker sample, as presented above, monetary policy strongly impacts the federal budget.²⁶ The size of the blue bars relative to the contribution of taxes in the later periods visualizes that government spending does much more of the heavy lifting in bringing debt back to steady state, compared to higher tax rates.

6.3 Scenario analyses and policy implications

Having established that the estimated HANK model is a useful laboratory to 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

²⁶Auclert, Rognlie, and Straub (2020) analyze and estimate a HANK model with long-term government debt and argue that the fiscal response to monetary policy is not a strong channel 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 only by -0.06% . The empirical evidence presented above (Figure 1 in section 3) yields a -0.36% fall instead, in line with the modern literature on the effects of monetary policy, see the discussion and references in section 3.3.

Figure 7: Counterfactual: no business-cycle stabilization motive of the government



Notes: Impulse response functions (IRFs) to a monetary policy shock in both HANK and RANK. All variables are shown as percent deviations from steady state.

shapes the effects of monetary policy. To that end, I apply the following restriction to the parameters of the estimated HANK model: $\gamma_Y^\tau = \gamma_\pi^\tau = \gamma_Y^B = \gamma_\pi^B = 0$, 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 somewhat, 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 debt repayment motive. As a consequence, output drops by roughly one-third more on impact since the stabilizing, systematic reaction of taxes is missing. The higher tax rates lead to a less pronounced rise in the debt level, but the pace of repayment is unchanged and therefore still very slow. Specifically, the endogenous response by the tax rate to output, γ_Y^τ , is the key parameter responsible for the strong output losses. To show this, figure D.1 in the appendix provides a counterfactual scenario in which only the (anyway insignificant) systematic reaction to inflation is restricted ($\gamma_\pi^\tau = \gamma_\pi^B = 0$), with only very modest changes

in the output response.

The last row presents the same counterfactual in the RANK model. As Table 3 suggests, the fall in the tax rate in RANK does not induce the same level of output stabilization as it does in HANK. The fact that the output response in the counterfactual is almost unchanged results, however, not only from small effects of tax rate changes, but also from the fact that the RANK model estimates a procyclical government spending response. Its suspension ($\gamma_Y^G = 0$) results in higher output, offsetting the output losses due to the higher tax rate.

All in all, the counterfactual scenario in the HANK model suggests that the fiscal channel of monetary policy, an endogenous reaction of taxes and spending to economic conditions, offsets the output losses induced by a higher interest rate by roughly one-third. However, this is the estimated, average response of fiscal policy in the data. In times of limited fiscal capacity, the government might not have the fiscal “space” to issue more debt for expansionary tax policy. In such a scenario, illustrated in the counterfactual by the absence of fiscal stabilization policy, the tax rate immediately increases, increasing tax revenues, leading to a less pronounced increase in government debt. Pushing this inability further to even more limited debt increases would entail even stronger tax increases or government spending cuts, which would deteriorate output further. This dependence renders the fiscal capacity of the government an important statistic of policy relevance for the conduct of monetary policy.

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, is empirically disciplined by new evidence on the causal effects of U.S. monetary policy on the complete 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 fiscal policy rules show that the fiscal response is to the monetary induced economic conditions, not to the interest rate movement itself. The estimated HANK model is used to quantify the effects monetary policy would have in the absence of fiscal stabilization policy, which implies output losses would be one-third 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 lead to greater output losses. This result readily connects to the analogous literature that documents that the fiscal multiplier depends on the monetary reaction, which has received empirical support. Likewise, the prediction for this state-dependence of monetary policy effects is testable and appears a promising avenue for future research.

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Appendices

The appendices provide (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 cyclical component of GDP, 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 (FYGFDUN)
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)
Avg. tax rate	Average total effective tax rate	Sum of average personal income tax rate and average corporate tax rate. Follows Mertens and Ravn (2013).	FRED
Real market value of debt	Per capita	Divided by CPI and population	FRED (MVGFD027MNFBRBDAL)
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. tax rate (taxsim)	Average effective income tax rate	See text for a description	TAXSIM, NBER
Marg. income tax rate	Marginal income tax rate		TAXSIM, NBER
Output	Cyclical component of Real per-capita log x 100 GDP	Cyclical component is computed using the Hamilton (2018) filter. GDP (GDPC1) divided by population.	FRED

Monetary policy proxy	High-frequency yield surprise	First principle component of several high-frequency variables around FOMC announcements	Bauer and Swanson (2023a)
Main shock	Business-cycle	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.

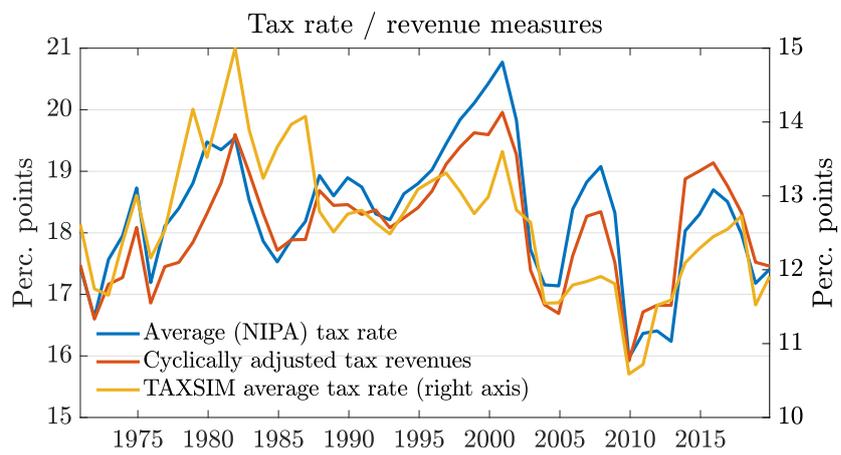
A.2 Data for model calibration

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 (FDHBPIN), divided by capital.
3. **Wealth Gini:** World Inequality Database: <https://wid.world/country/usa/>
4. **Fraction of hand-to-mouth households:** Kaplan, Violante, and Weidner (2014) report based on the Survey of Consumer Finances, waves 1989 – 2010, that about 31% of the U.S. population is hand-to-mouth.
5. **Government spending to output ratio:** Government consumption and investment (GCE) divided by GDP.
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.

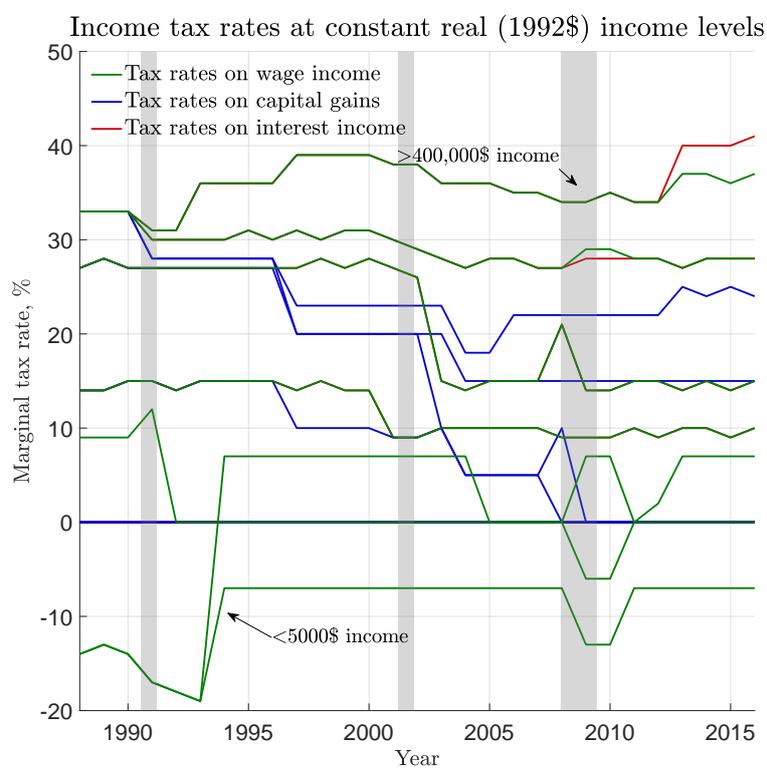
A.3 Variation in tax policy

Figure A.1: Changes in the tax code and comparison of tax rate measures



Source: NIPA, CBO, TAXSIM, and own calculations.

Figure A.2: Changes in the tax code for different income levels

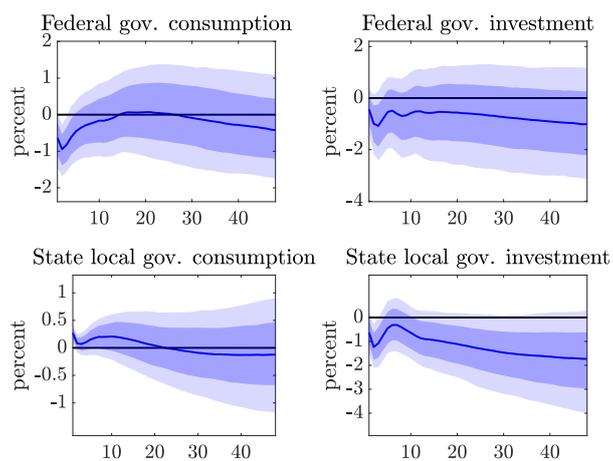


Source: TAXSIM, and own calculations.

Appendix B Further VAR results

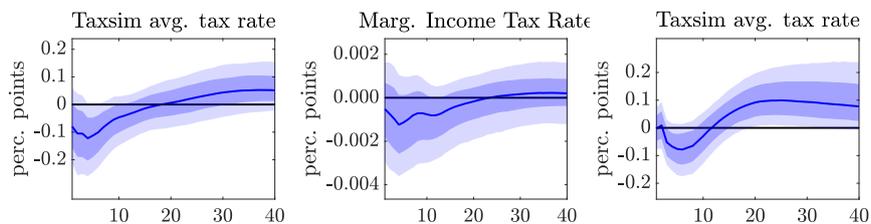
B.1 Additional results to monetary shocks

Figure B.1: MF-BVAR: responses of government spending components



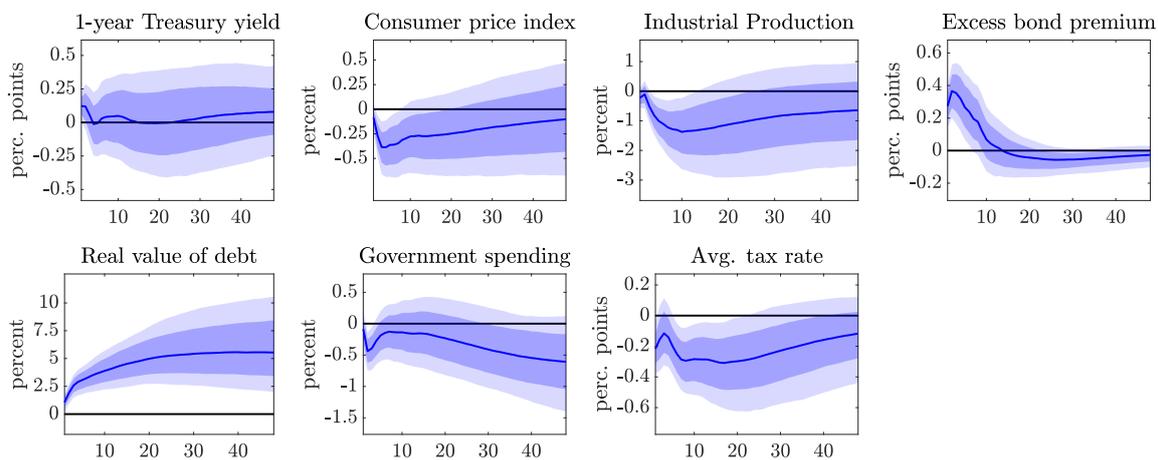
Notes: Impulse response functions to a 25bp shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.2: MF-BVAR (quarterly-annual): 10-year responses of tax rates



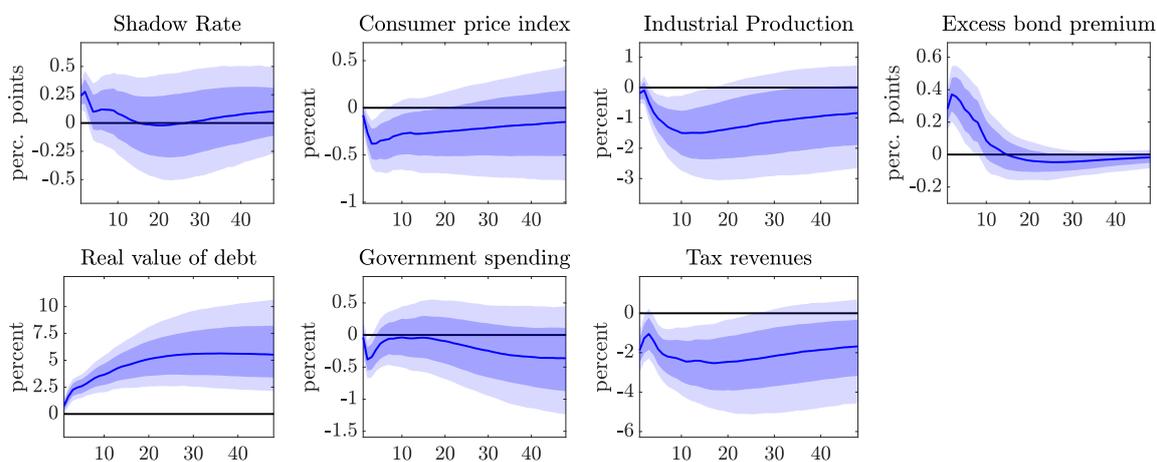
Notes: Impulse response functions to a 25bp monetary shock (panels 1 – 2), or to the MBC shock (panel 3). Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

Figure B.3: MF-BVAR: Robustness to the 1-year treasury yield



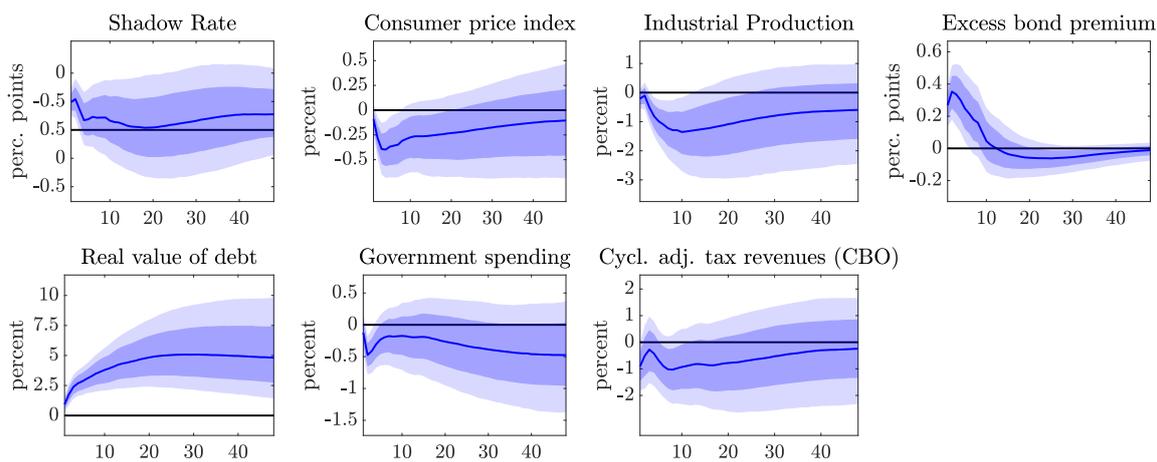
Notes: Impulse response functions to a shock of the same size that increases the shadow rate by 25bps in the baseline results (1). Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.4: MF-BVAR: Robustness exercise with federal tax revenues



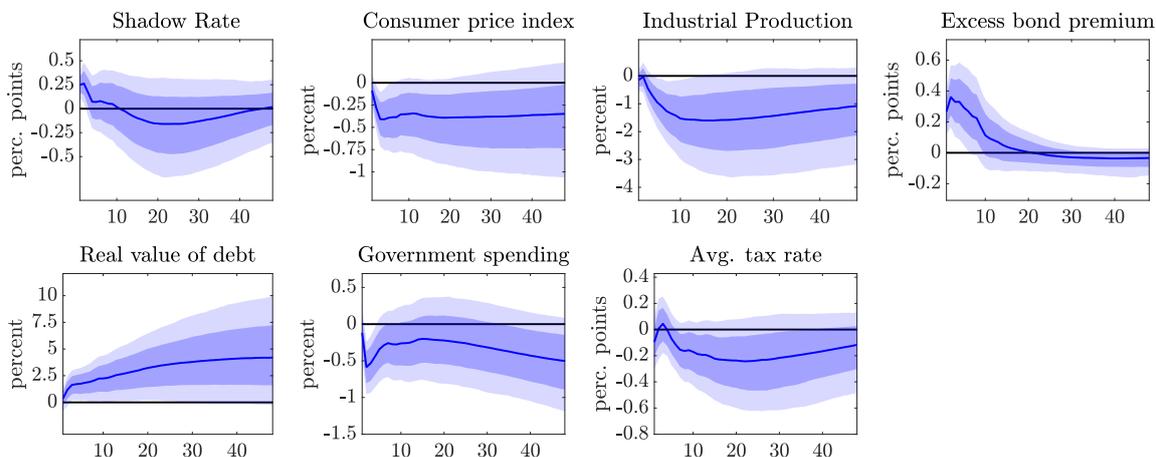
Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.5: MF-BVAR: Robustness exercise with cyclically adjusted federal tax revenues



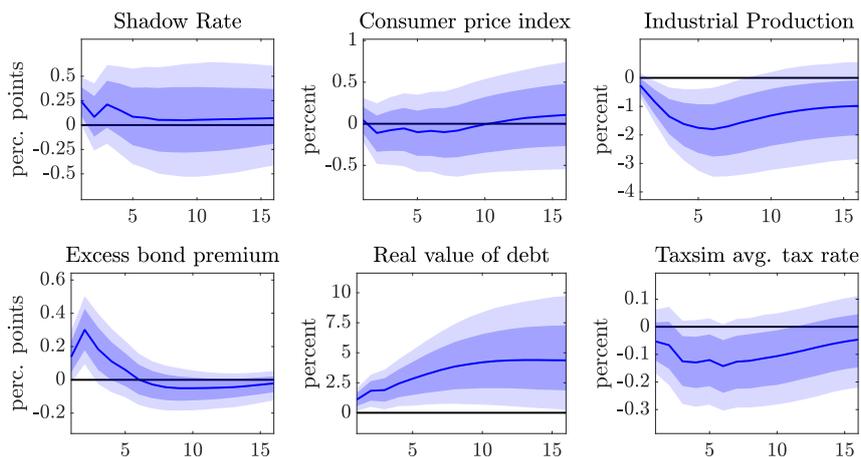
Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.6: MF-BVAR: Robustness exercise excluding the Zero Lower Bound



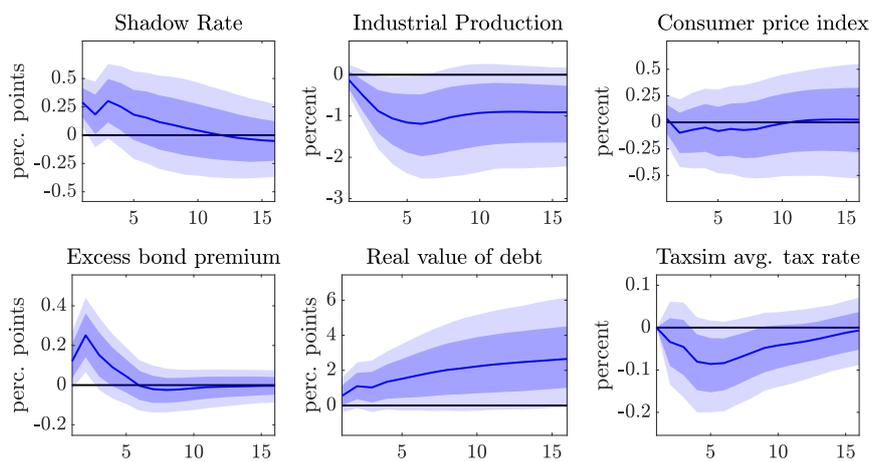
Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.7: MF-BVAR: quarterly - annual model, 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.

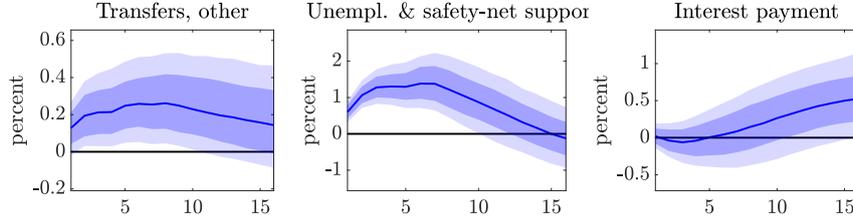
Figure B.8: MF-BVAR: quarterly - annual model, zero restriction on contemporaneous tax response



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

B.2 Additional results for the MBC shock

Figure B.9: MF-BVAR: Transfer and interest payment responses to the MBC shock



Notes: All three variables have been added to the baseline 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.

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 $\{w_t, w_t^F, \Pi_t^F, \Pi_t^U, q_t, q_t^B, r_t, \pi_t, \pi_t^w\}$, 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.

Appendix D Further New Keynesian model estimation results

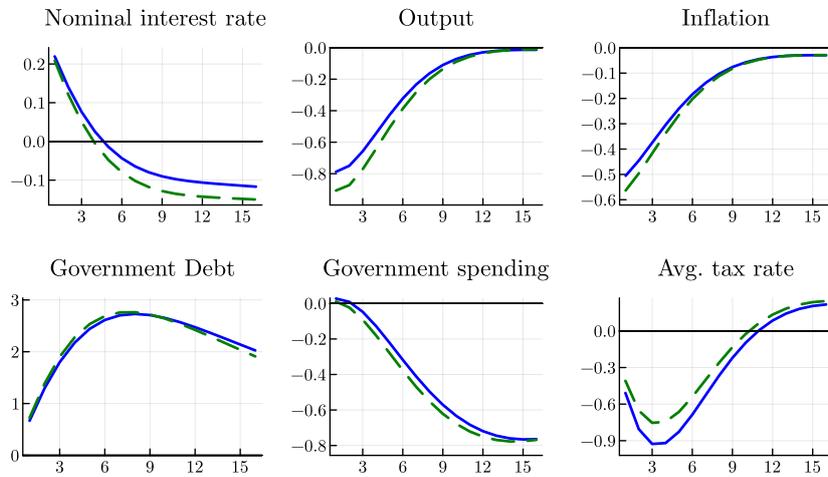
D.1 Further results

Table D.1: Estimation results, extended fiscal policy rules

	MP, baseline	MP, extended	MBC, baseline	MBC, extended
<i>(A.) Tax Rule</i>				
γ_B^T	0.14	0.12	0.23	0.09
γ_Y^T	1.54	1.68	1.42	0.90
γ_π^T	1.03	0.43	0.77	0.46
γ_R^T		0.12		-0.63
<i>(B.) Govern. Spending Rule</i>				
γ_B^G	-0.36	-0.21	-0.37	-0.29
γ_Y^G	-0.07	-0.17	-0.17	0.20
γ_π^G	-0.22	0.00	-0.24	-0.99
γ_R^G		0.11		0.17

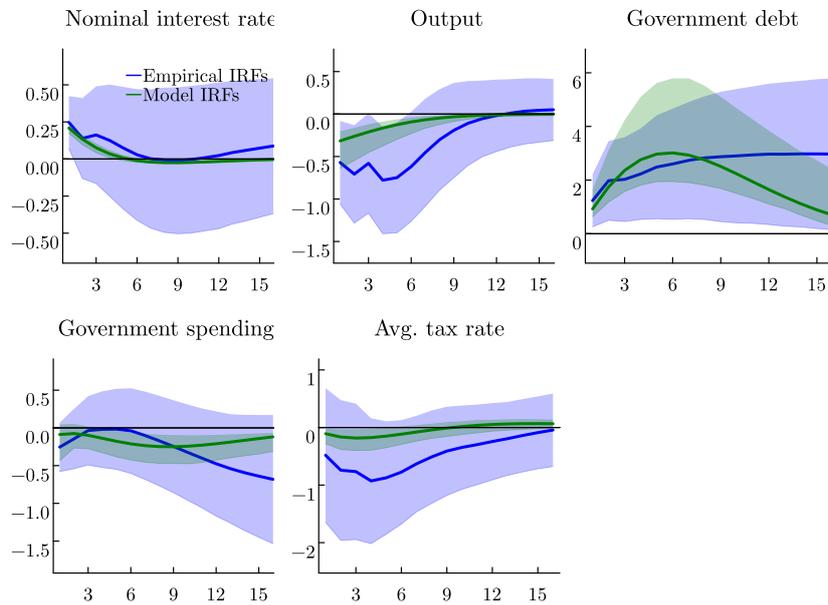
Notes: MP = Monetary Policy shock, MBC = Main Business-Cycle shock.

Figure D.1: Counterfactual: no response to inflation



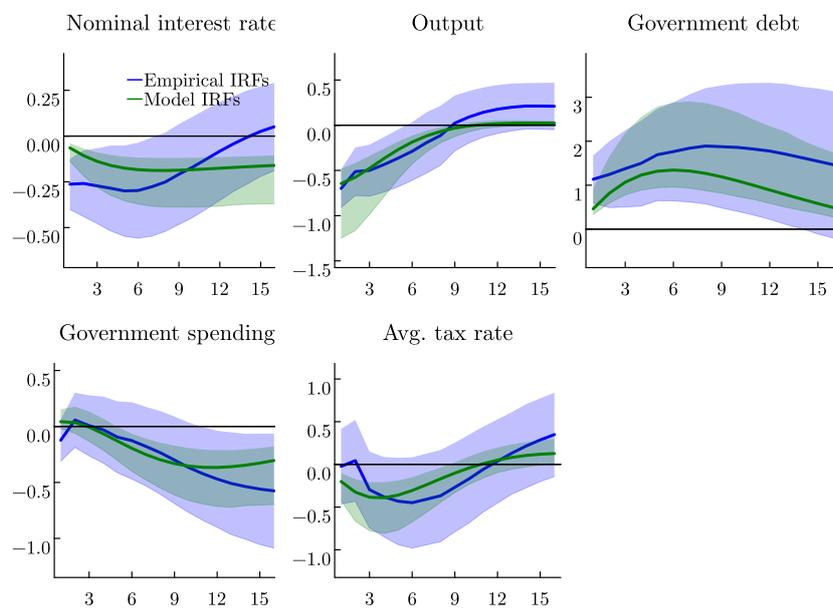
Notes: Impulse response functions (IRFs) to a monetary policy shock in HANK. All variables are shown as percent deviations from steady state.

Figure D.2: 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.

Figure D.3: Impulse response matching of the HANK model to the MBC-shock



Notes: Impulse response functions to the MBC-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.

Table D.2: Prior and Posterior Distributions of Estimated Parameters, demand shock

Parameter	Prior			Posterior
	Distribution	Mean	Std. dev.	Posterior Mean (MBC shock)
<i>Frictions</i>				
δ_s	Gamma	5.00	2.00	4.93 [2.4 8.3]
ϕ	Gamma	4.00	2.00	4.75 [2.3 8.0]
κ	Gamma	0.1	0.02	0.114 [0.09 0.15]
κ_w	Gamma	0.1	0.02	0.098 [0.07 0.13]
<i>Taylor rule</i>				
ρ_R	Beta	0.85	0.1	0.98 [0.97 0.99]
θ_π	Normal	2.0	0.3	1.81 [1.41 2.18]
θ_Y	Normal	0.125	0.05	0.23 [-0.08 0.54]
<i>Exogenous demand shock process</i>				
ρ_A	Beta	0.5	0.2	0.92 [0.85 0.96]
σ_A	Inv. Gamma	0.05	0.02	0.06 [0.035 0.09]
<i>Fiscal rules</i>				
ρ_G	Beta	0.5	0.2	0.79 [0.53 0.93]
$-\gamma_B^G$	Gamma	0.5	0.25	0.37 [0.22 0.59]
γ_Y^G	Normal	0.0	1.0	-0.17 [-0.95 0.61]
γ_π^G	Normal	0.0	1.0	-0.24 [-1.53 1.07]
ρ_τ	Beta	0.5	0.2	0.83 [0.69 0.93]
γ_B^τ	Gamma	0.5	0.25	0.23 [0.09 0.42]
γ_Y^τ	Normal	0.0	1.0	1.42 [0.46 2.43]
γ_π^τ	Normal	0.0	1.0	0.77 [-0.65 2.17]

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

D.2 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 100.000 draws from the posterior distribution is used to compute the posterior statistics (discarding 30.000 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 tests 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.4 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)	
	z-stat	p-value	z-stat	p-value	z-stat	p-value
δ_s	-0.787	0.431	0.833	0.405	-0.827	0.408
ϕ	0.123	0.902	-2.498	0.013	-2.054	0.040
κ_Y	-0.097	0.923	0.993	0.321	1.515	0.130
κ_w	-0.281	0.779	-1.126	0.260	0.109	0.913
ρ_A	–	–	–	–	-0.257	0.798
σ_A	–	–	–	–	1.919	0.055
ρ_R	0.469	0.639	1.026	0.305	-1.638	0.101
σ_R	0.768	0.443	-0.962	0.336	–	–
θ_π	-0.471	0.638	-1.133	0.257	-0.550	0.582
θ_Y	1.026	0.305	-0.574	0.566	0.529	0.597
ρ_G	-0.960	0.337	-2.392	0.017	0.422	0.673
$-\gamma_B^G$	-1.524	0.128	-1.268	0.205	1.313	0.189
γ_Y^G	-0.224	0.823	3.930	0.000	0.339	0.734
γ_π^G	-1.051	0.293	-1.020	0.308	0.044	0.965
ρ_τ	0.497	0.619	0.913	0.361	0.187	0.852
γ_B^τ	-0.219	0.827	-0.288	0.773	-1.158	0.247
γ_Y^τ	2.360	0.018	0.108	0.914	-0.730	0.465
γ_π^τ	-2.843	0.004	-0.125	0.901	0.114	0.909

Figure D.4: Trace plots, baseline model

