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Quantifying the Fiscal Channel of Monetary Policy

Frederik Kurcz

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DIW Berlin
German Institute for Economic Research
Mohrenstr. 58
10117 Berlin

Tel. +49 (30) 897 89-0
Fax +49 (30) 897 89-200
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Quantifying the Fiscal Channel of Monetary Policy*

Frederik Kurcz†

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Abstract

In macroeconomic models featuring borrowing-constrained agents, the effects of monetary policy depend on the fiscal reaction to interest rate changes. This paper presents new evidence on the dynamic causal effects of U.S. monetary policy shocks on fiscal instruments and estimates a Heterogeneous Agent New Keynesian model with fiscal feedback rules to match 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.

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

JEL Codes: E21, E52, E60, E63

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†DIW Berlin, Berlin School of Economics, and Free University Berlin. Contact: Mohrenstrasse 58, 10117 Berlin, fkurcz@diw.de. Website: https://frederikkurcz.github.io

1 Introduction

Heterogeneous Agent New Keynesian (HANK) models are rapidly replacing their representative agent counterpart in the analysis of monetary policy. By featuring borrowing-constrained agents, in those models agents' consumption decisions are not invariant to fiscal policy anymore. In fact, Kaplan, Moll, and Violante (2018) show that different assumptions on financing higher interest rates on debt turn out to be one of the most important determinants of the aggregate effects of monetary policy. As a result, any exploration of monetary policy in HANK models depends crucially on the set of fiscal rules governing the instruments at the fiscal policy maker's disposal. Against this background, the present paper takes up the following 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 estimating a model that goes beyond a stylized role for the government and instead allows fiscal policy to feature more generally in the monetary transmission mechanism. To that end, this paper studies a HANK model with rich household heterogeneity and portfolio choice which is augmented by flexible feedback rules for government spending and taxes. The identification of the unknown parameters of the fiscal policy rules exploits exogenous variation in monetary policy: I present new evidence on 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 the HANK model by Bayesian impulse response matching. Thus, the fiscal block of the model is empirically disciplined and allows, via a series of counterfactuals, the characterization and quantification of the fiscal channel of monetary policy. I find that, first, U.S. fiscal policy reacts with countercyclical tax and transfer policies to a monetary-induced contraction in output, which are accommodated by taking on more debt. The estimated systematic response of fiscal policy is not to higher interest rates *per se*, but rather to economic conditions. Second, government spending is insensitive to economic conditions but is the main fiscal margin of adjustment to finance debt deviations, albeit very slowly. Third, the total systematic fiscal response shapes the aggregate effects of monetary policy substantially, but this result is only in part due to the need to finance higher interest rate costs on government debt. Instead, a counterfactual exercise shows that without the countervailing tax rate decline to stabilize output, the effects of monetary policy would be roughly one third more contractionary.

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. 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.[1] 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

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

U.S. 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. To estimate the parameters governing the dynamics of the model, I employ Bayesian impulse response function matching (Christiano, Trabandt, and Walentin, 2010).[2]

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 the business cycle. Allowing the fiscal policy rules to react to inflation and the interest rate in addition to output and government debt shows that the estimated reaction by fiscal policy to the monetary policy shock is not to the interest rate *per se*: the estimated interest rate-coefficient in both fiscal policy rules is economically insignificant. Tax rates react to inflation, but to a lesser extent than to output. These estimated fiscal policy rules are conditional on a monetary policy shock, but they hold more generally: 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. Furthermore, the result that the monetary shock is counteracted by a stabilization motive of the fiscal authority resonates with the analogous case, well-known in the literature: fiscal stimulus, by increasing output and inflation, is counteracted by monetary policy by operating a standard Taylor rule (see, e.g., Christiano, Eichenbaum, and Rebelo (2011), Woodford (2011), Cloyne, Jordà, and Taylor (2020)).

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. In contrast, the counterfactual evolution of inflation is more muted. The results call for a better understanding of the division of labor in macroeconomic stabilization policy.

Related literature. This paper is related to three strands in the literature. The first 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,

[2]An alternative approach to estimating the model is likelihood-based full-information Bayesian estimation, which requires specifying the full set of structural shocks that drive the business cycle. However, the appeal of impulse response function matching is to sidestep the need to add "dubiously structural" shocks to the analysis (Chari, Kehoe, and McGrattan, 2009), as well as the vulnerability to weak identification concerns raised in Fernández-Villaverde, Rubio-Ramírez, and Schorfheide (2016).

Rognlie, and Straub (2020) 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. Relative to these papers, I allow for a general, flexible role played by fiscal policy in monetary transmission that is disciplined by empirical evidence.

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 contrast to my paper, both of these 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 (cf., Fernández-Villaverde et al. (2007)) to evaluate an approximation to the desired counterfactual (Caravello, McKay, and Wolf (2024) hence 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 estimating DSGE models and specifically 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), Kliem and Kriwoluzky (2014), Bayer, Born, and Luetticke (2024), and Bilbiie, Primiceri, and Tambalotti (2023). But in contrast to this paper, none employ impulse response function matching specifically to monetary policy (or aggregate demand) shocks. 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. Therefore, the contribution to this literature is to estimate fully parameterized fiscal rules conditional to monetary policy, which are shown to matter substantially for monetary transmission.

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

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

$$r_t = \phi_\pi \pi_t + \phi_Y Y_t + \varepsilon_t^R, \tag{2}$$

where $\boldsymbol{x}_t$ 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. In the Representative Agent New Keynesian (RANK) literature, there is usually no role for fiscal policy, not in textbook models (Galí, 2015), nor in its medium-scale variety (Smets and Wouters, 2007). In a RANK environment, it is possible to ignore the government because of the assumed existence of lump-sum transfers that balance the governments budget without changing any resource allocation due to Ricardian Equivalence. However, if Ricardian Equivalence fails and changes to fiscal instruments have implications for agents' decisions, as is the case in models with more than one agent, finite lives, or imperfect foresight (among others), the fiscal response to interest rate changes becomes a central propagation mechanism, as Kaplan, Moll, and Violante (2018) show. Arguably, models in which Ricardian Equivalence fails are by now the standard in business-cycle macroeconomics; see Kaplan, Moll, and Violante (2018) for monetary policy, Auclert, Rognlie, and Straub (2018) for fiscal policy, and Gabaix (2020) for an example of behavioral models. The goal in breaking Ricardian Equivalence is typically to allow for high marginal propensities to consume (MPCs), a robust pattern in the data. In these type of business cycle models, the analysis of monetary policy crucially depends on assumptions for fiscal policy rules. It is precisely the high MPCs that make the transmission of monetary policy through the fiscal policy reaction 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. At business-cycle frequencies, there is little and mixed evidence on these fiscal policy rules; conditional on a monetary policy shock, they are unknown. As a result, for the fiscal channel of monetary policy, the parameterization 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.

$$\tau_t = \gamma_Y^\tau Y_t + \gamma_B^\tau B_t + \nu_t^\tau \tag{3}$$

$$G_t = \gamma_Y^G Y_t + \gamma_B^G B_t + \nu_t^G \tag{4}$$

The inclusion of economic conditions in the form of output Y_t captures a business cycle stabilization motive of fiscal policy. These feedback rules are still parsimonious, since inflation and the interest rate could in principle be important inputs, which will be investigated in later sections. Even so, most models of monetary policy feature $\gamma_Y^\tau = \gamma_Y^G = 0$ and either $\gamma_B^\tau \geq 0, \gamma_B^G = 0$ or vice versa (see, e.g., Kaplan, Moll, and Violante (2018), Auclert, Rognlie, and Straub (2020)). 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 demand, mainly via monetary policy shocks. 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 aggregate demand that move both output and government debt, we can elicit the endogenous response of fiscal policy.

This strategy then involves estimating impulse response functions as the key macro moments in the data, which will be carried out in the next section.[3] With empirical impulse response functions at hand, the non-policy block of the model will be completely specified by deriving equilibrium relations from a state of the art theoretical model of monetary policy transmission. The parameters governing the dynamics of the model (1) - (2) as well as the complete 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 Het-

[3] Caldara 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.

erogeneous 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 dynamic causal 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 evidence.

3.1 Time series framework

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

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

where $\boldsymbol{\varepsilon}_t$ is the unobserved white noise vector of exogenous fundamental shocks $\boldsymbol{\varepsilon}_t \sim \text{WN}(\boldsymbol{0}, \boldsymbol{I}_{n_{\boldsymbol{\varepsilon}}})$. The coefficient matrices $\boldsymbol{\Theta}_l$, 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:

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

Under weak conditions, the SVMA model admits a VAR representation and thus can be estimated with standard reduced-form methods. In particular, the following analysis relies on the estimation of a 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 $\tilde{\boldsymbol{y}}_t = (z_t, y_{1,t}, \dots, y_{n,t})'$, the so-called "internal-instrument" approach recommended by Plagborg-Møller and Wolf (2021), the only assumptions for identification are the SVMA model (5) and the IV exclusion restriction (6). In particular, structural impulse response functions $\boldsymbol{\Theta}_l$ can still be consistently estimated even if the monetary policy shock is noninvertible (i.e., if $\varepsilon_{1,t} \notin \text{span}(\{\tilde{\boldsymbol{y}}_\tau\}_{-\infty<\tau<t})$). 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 financal contracts around Federal Open Market Commitee (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.[4] 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 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, 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

[4] In 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.

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 causal 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 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).[5] The proxy by Bauer

[5] The hyperparameters λ_1 to λ_5 governing the prior are set as follows: the prior tightness for the autoregressive coefficients of order one, λ_1, and for higher lags λ_2 are set to 5 and 1, respectively, as in Litterman (1986). All remaining hyperparameters, the sum-of-coefficients prior, co-persistence prior of the data, and the weight of the prior on the covariance matrix of the innovations (a diagonal matrix with elements equal to the

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.

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 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).[6] 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. 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.[7] Therefore, it encompasses all possible margins of the tax schedule that could be adjusted. In summary, Figure 1 suggests that tax policy becomes expansionary after a contractionary monetary shock, alongside an increase in the stock of debt and a gradual decline in government spending.

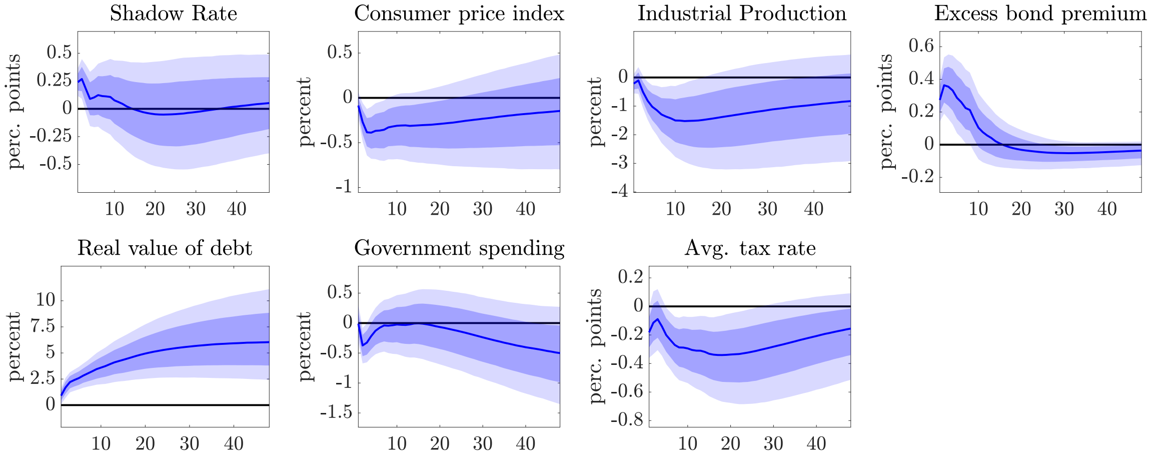
Next to government debt, spending, and taxation, a key instrument of fiscal policy is transfers. To keep the dimensionality of the VAR manageable, further fiscal variables are added to the baseline model in Figure 1 one by one. Figure 2 shows Unemployment and other safety-net support benefits, all other 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

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.

[6] Specifically, for the specifications that are closest to mine 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.

[7] For 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

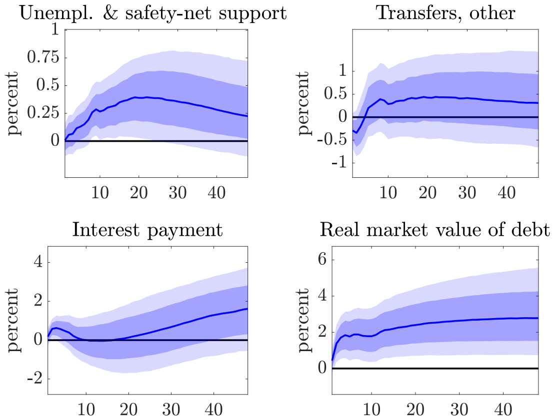


Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

benefits increase likely mechanically. All other transfer payments hardly respond. 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. The higher debt servicing costs as a result of the interest rate increase is a key mechanism in business cycle models without Ricardian equivalence, as highlighted by Kaplan, Moll, and Violante (2018). To keep the budget balanced in a model with one-period debt, the higher costs require an immediate financing decision - either reducing expenditures or deficit-financing the higher costs and repaying the debt over a long time period. However, U.S. federal debt is not rolled over every period (e.g. quarter), rather the average maturity of federal debt is roughly 5 years in the sample of this analysis (Treasury, 2023). In line with the 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 interest rate on newly issued debt, but increases total interest payments mechanically since the stock of debt increases.[8] 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

[8] Consistent 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.6.

Figure 2: MF-BVAR: Further fiscal responses to a monetary policy shock



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

estimation of the HANK model.

Appendix B.1 contains results to robustness exercises concerning the monthly-quarterly model presented so far. Figure B.1 shows that the results are robust to using the 1-year Treasury yield instead of the Shadow Rate, and Figures B.2 and B.3 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).

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 spending 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 tricky 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.[9] Using household data to fix the income distribution of taxpayers in 1984 and correcting the distribution each

[9]For 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.

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.

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 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.4 and B.5 in the appendix.[10] 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.

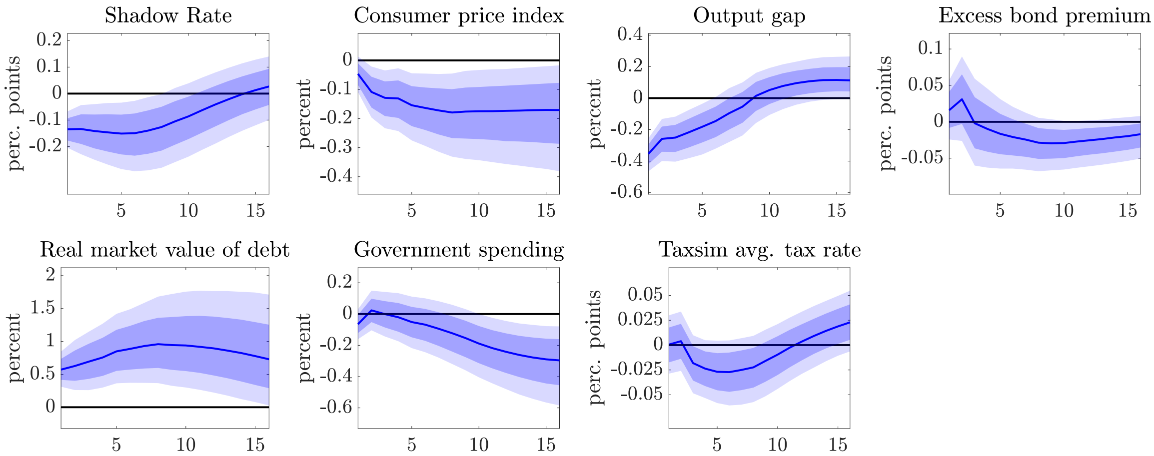
A robustness check on whether taxes are actively adjusted can be conducted by using another measure of changes in tax rates, namely cyclically adjusted federal tax revenues by the Congressional Budget Office (CBO). By purging federal tax revenues from fluctuations due to economic conditions, in principle, 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.3 it is shown that this measure falls as well. The difference in the impulse response to that of unadjusted tax revenues (Figure B.2) 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.

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 causal 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),

[10] Romer 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.

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 a standard deviation shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in quarters.

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 the output gap (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.[11] The MBC shock depresses the output gap on impact, as is the case for GDP in Angeletos, Collard, and Dellas (2020); leads to the price level falling, and a mild increase in the excess bond premium. The shadow rate falls immediately, consistent with accommodative monetary policy. Finally, the fiscal variables respond very

[11]The responses of industrial production and the book value of debt are very similar.

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.6 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.

While the fact that the TAXSIM tax rate also drops for the MBC-shock constitutes tentative evidence that it's not about interest rates fiscal policy is reacting to, a rigorous answer can be provided by estimating the systematic fiscal policy rules. In fact, what we can learn about a fiscal channel of monetary policy only from the empirical impulse responses is limited. 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 are the failure of Ricardian Equivalence, as well as 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

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

where x_{it} is the composite demand of household i for goods consumption c_{it} and leisure $(1-n_{it})$.[12] ξ denotes the constant relative risk aversion parameter and γ the Frisch elasticity of

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

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

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 $\log -\text{AR}(1)$ 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, Dıaz-Giménez, and Rıos-Rull (1998), helps to match the income and wealth distribution, but also solves the challenge of allocating pure rents in the economy without distorting factor prices or introducing a tradeable claim to the profit shares. The idiosyncratic productivity process is therefore described as

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

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

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

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 $\log -\text{AR}(1)$ 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 the the liquidity of bonds.

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 variaties is given by

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

Finally, taking all the above income components together, the household's budget constraint reads:

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

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 $\underline{\mathrm{B}}$ 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 aggregates states, value functions are treated as time-dependent. Furthermore, letting $'$ denote the next period values and dropping the indexes to the idiosyncratic states, the household's dynamic programming problem is then summarized by the following Bellman equations:

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

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

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

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 tractibility 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.[13]

4.2.1 Unions and labor packers

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

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

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

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

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

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

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

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

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

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

4.2.2 Intermediate Goods Producers

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

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

featuring variable capital utilization u_t, to produce the homogeneous output good Y_t.[14] 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:

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

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

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

where q_t is the price of capital goods.

4.2.3 Final Goods Producers

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

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

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

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

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

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

4.2.4 Capital Goods Producers

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

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

The optimality condition is given by

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

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

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

4.3 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.

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

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

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

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

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

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:

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

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

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

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 $1984-2019$.[15] Table 1 summarizes the parameters of the model that are calculated either directly from long-run time series averages to represent steady state ratios, or internally calibrated to match such targets. Specifically, the moments are: (i) the average ratio of illiquid assets/capital to (annual) output, $\frac{K}{Y} = 2.83$, (ii) the average liquid assets to (annual) output, $\frac{B}{Y} = 0.45$, (iii) the fraction of poor hand to mouth households of 17% (Kaplan, Violante, and Weidner, 2014), and (iv) the top 10% wealth share of 68%. All calibrated parameters are determined jointly. The preference parameters ξ and γ are set to standard values in the literature, and the persistence and variance of the autoregressive idiosyncratic productivity process to the values found in Storesletten, Telmer, and Yaron (2004). ι gives the transition probability from entrepreneur to worker, which is matched with the probability to fall out of the top 1% of the income distribution of the U.S. in a given year according to the estimates in Guvenen, Kaplan, and Song (2014). The borrowing limit and the portfolio adjustment probability are set to match the share of poor 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). $\boldsymbol{y_t}$ 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*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

[15]For the data sources and definitions used in the calibration, see Appendix A.2.

Table 1: Calibrated parameters in the HANK model

Parameter	Value	Description	Target or source
Households			
ξ	2.0	Relative risk aversion	Standard value
β	0.981	Subjective discount factor	$K/Y = 2.83$
γ	2.0	Inverse of Frisch elasticity	Chetty et al. (2011)
λ	4.40%	Portfolio adjustment probability	$B/Y = 0.45$
$\underline{\mathrm{B}}$	0.0	Borrowing constraint	Share of poor hand-to-mouth = 17%
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.	Top 10% wealth share = 0.68%
Firms			
α	0.68	Share of labor	Bayer, Born, and Luetticke (2023)
δ_0	1.6%	Depreciation rate	6.3% p.a.
$\bar{\eta}$	11	Elasticity of substitution	Price markup 10%
$\bar{\zeta}$	11	Elasticity of substitution	Wage markup 10%
Government			
$\bar{\tau}$	0.28	Tax rate level	$G/Y = 19\%$
$\bar{R}_b$	1.00	(Gross) Nominal rate	Real MZM own rate ≈ 0

rate, the output gap, 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 the output gap, the cyclical component of real per-capita GDP computed using the Hamilton (2018) filter, which is more in line with the output gap concept in the model, Y_t. In this application, the parameter vector is given by[16]

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

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 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 esti-

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

Table 2: Estimated parameters in the HANK model

Parameter	Prior			Posterior
	Distribution	Mean	Std. dev.	Posterior Mean
		Frictions		
δ_s	Gamma	5.00	2.00	3.73
ϕ	Gamma	4.00	2.00	3.52
κ_Y	Gamma	0.1	0.02	0.079
κ_w	Gamma	0.1	0.02	0.087
		Taylor rule		
ρ_R	Beta	0.85	0.1	0.98
σ_R	Inv. Gamma	0.05	0.02	0.057
θ_π	Normal	2.0	0.3	1.82
θ_Y	Normal	0.125	0.05	0.127
		Fiscal rules		
ρ_G	Beta	0.5	0.2	0.62
$-\gamma_B^G$	Gamma	0.5	0.25	0.18
γ_Y^G	Normal	0.0	1.0	0.44
ρ_τ	Beta	0.5	0.2	0.82
γ_B^τ	Gamma	0.5	0.25	0.14
γ_Y^τ	Normal	0.0	1.0	1.87

mated 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 2 for the parameters 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, a standard prior mean parameterization is used but 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, and Luetticke (2023), with standard normal priors on the output coefficients. This completes the description of the baseline model specifications for the estimation on the monetary policy induced impulse response functions. The same calibration and priors are later used for the estimation with the MBC shock.

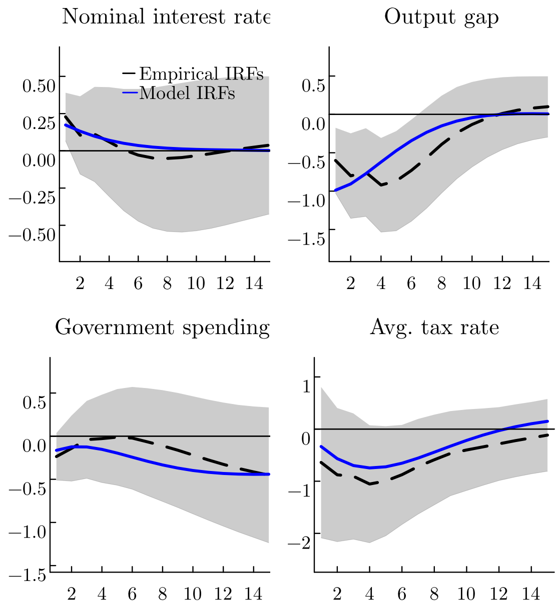
6 Estimated fiscal rules and the fiscal channel of monetary policy

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. Finally, the model is used to quantify the contribution of the fiscal reaction to the macroeconomic consequences of the monetary intervention.

6.1 Parameter estimates and model fit

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. 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. Conditional on the Main Business-Cycle shock, the interest rate smoothing parameter is equally large with 0.96, see table D.1, hence providing a consistent picture across estimation results on this parameter. Of main interest are the parameters of the fiscal policy rule. Both fiscal policy instruments exhibit much lower autocorrelation parameters than the interest rate, but unsurprisingly changes in the tax rule are more persistent than adjustments to government spending. The parameters governing the repayment of debt 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 0.18 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 (see, e.g., McKay, Nakamura, and Steinsson (2016), Auclert, Rognlie, and Straub (2020), McKay and Wolf (2022)). Furthermore, the pace of repayment is very slow: after the monetary shock, debt returns to its steady state value, in a scenario where the fiscal authority only repays debt, after 22 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 1.87. 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 relatively small and indicates that fiscal spending is pro-cyclical. However, it turns out that the feedback to a one percent output deviation of 0.44 is economically insignificant and dwarfed by the reaction of spending to debt, as will be shown below. 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

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



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

countercyclical tax policy to stabilize output.

Figure 5 shows that the estimated off-the-shelf HANK model is able to match the empirical impulse responses to the monetary shock well. Of note is the typical difficulty of DSGE models to produce hump-shapes in output endogenously, although the impulse response of the measure of output used here does not display a strong hump shape. To match the trough after 5 quarters as in the data, Auclert, Rognlie, and Straub (2020) show that a behavioral feature will go a long way.

For this model to constitute a good laboratory to study the fiscal channel of monetary policy, the model should not only fit evidence on the transmission of monetary policy, but also feature fiscal policy in line with empirical evidence. The key statistic describing the effects of tax and government spending policy is their output multiplier. 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 -1.06, and for the government spending multiplier it is 1.23. Both estimates are right in the middle of the ones typically found in the empirical literature surveyed by Ramey (2016).

Table 3: Estimation results, extended fiscal policy rules

	MP, baseline	MP, extended	MBC, baseline	MBC, extended
(A.) Tax Rule				
γ_B^τ	0.14	0.13	0.18	0.22
γ_Y^τ	1.87	1.22	1.56	1.09
γ_π^τ		1.47		0.45
γ_R^τ		−0.49		0.78
(B.) Govern. Spending Rule				
γ_B^G	−0.18	−0.19	−0.32	−0.29
γ_Y^G	0.44	0.46	−0.07	0.37
γ_π^G		−0.18		−0.74
γ_R^G		0.22		0.04

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

6.2 Does fiscal policy react directly or indirectly to interest rate changes?

The empirical evidence in section 3 showed that one direct consequence of an interest rate increase - higher interest rate payments on debt - are not of first-order concern in the short run. However, it is possible that fiscal policy reacts to more than output and considers interest rates a key macroeconomic condition in its systematic conduct. To test this, in this subsection the HANK model is re-estimated to allow for more flexible, extended fiscal policy rules. In particular, the feedback rules for taxes and government spending, Equations (29) - (30), now feature terms for inflation and the nominal short-term interest rate. The prior for these four parameters are standard normal, the same as for the output feedback-parameters.

Table 3 displays the estimates for the baseline specifications for both the monetary policy impulse response matching, as well as the MBC-shock impulse response matching results, as a comparison to the extended fiscal policy rules. Focusing on the results for the monetary shock, the addition of inflation and the interest rate in the policy rules does not materially affect the results. In particular, the coefficients on the interest rate in both the tax rate and government spending rules are very small. What is more, since the interest rate only moves by roughly 15 basis points (in quarterly terms), the variation in the fiscal instruments due to interest rates are economically insignificant. The coefficient on output decreases relative to the baseline, but is now supplemented with a positive coefficient on inflation, which points in the same direction: after a drop in output and inflation, tax rates decrease. As a result, the estimated parameters support the intuition from section 3 that the fiscal authority does not react to movements in the interest rate itself but rather to economic conditions, first and foremost output, but also to inflation.

Taking this argument one step further, if the fiscal reaction is not to the interest rate *per se*, the parameter estimates of the fiscal policy rules should look very similar if the estimation is conditional on a more general non-monetary demand shock. The last two columns of table 3 confirm that this is indeed the case. "MBC-shock" refers to an estimated model based on impulse response matching to the "Main Business-cycle-shock" from Angeletos, Collard, and Dellas (2020), arguably an aggregate demand disturbance.[17] The starkest difference between the shocks is the interest rate response. Even though it has the opposite sign, neither the impulse responses of the fiscal variables, nor the parameter estimates of the fiscal policy rules are much changed.

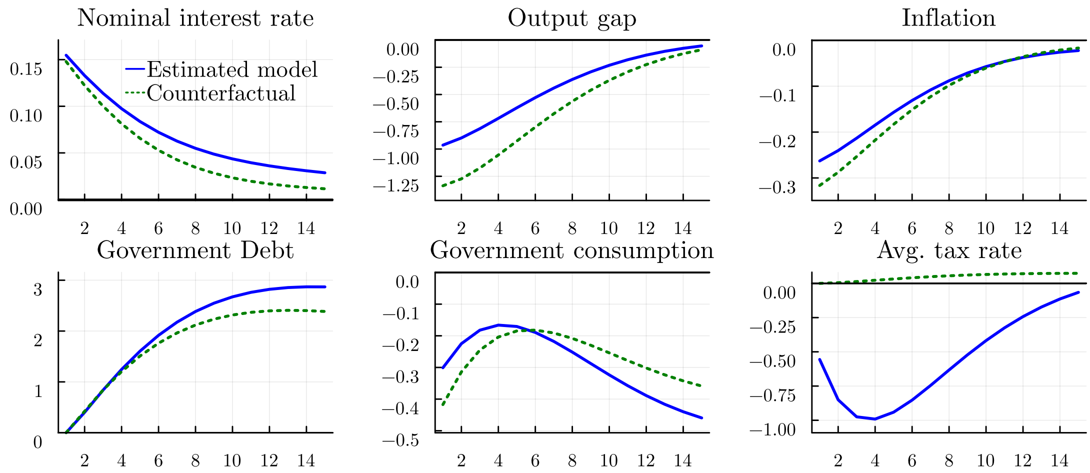
The estimates in tables 2 and 3 are in line with recent evidence by Caldara and Kamps (2017), despite a very different identification strategy utilizing technology, oil and Romer and Romer (2004) shocks. Specifically, they estimate a strong positive output coefficient in the tax rule, alongside a coefficient 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 results in table 3. 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 easily adjusted. The absence of a strong feedback from output to government spending also corroborates earlier work by Perotti (2005) and McKay and Reis (2016) who relied on this assumption.

6.3 Counterfactual exercise

Finally, Figure 6 presents a counterfactual exercise in which the fiscal authority suspends the business-cycle stabilization motive of tax policy, i.e., $\gamma_Y^\tau = 0$. The aim is to quantify the contribution of the fiscal channel in shaping the effects of monetary policy. Therefore, the impulse response matching exercise requires now to match the trough average tax rate response exactly, in order to be precise about the most important fiscal variable (at only very little cost of fit for the other variables). In this counterfactual scenario, depicted in dotted green, the average tax rate does not decline, but instead rises somewhat, due to the increase in debt. Government consumption is relatively unaffected since its evolution is dominated by the debt repayment motive. As a consequence, output drops by roughly one third more on impact since the tax stimulus from fiscal policy is missing. The higher tax rates lead to a slightly less pronounced rise in the debt level, but the pace of repayment is still very slow. The

[17] For the full table of parameter estimates for the baseline fiscal rules, see table D.1, and for the impulse response matching fit, see Figure D.1 in the appendix.

Figure 6: Counterfactual: no business-cycle stabilization motive ($\gamma_Y^\tau = 0$)



effect on inflation is similar qualitatively, but more muted. The fiscal channel of monetary policy therefore constitutes an indirect channel that dampens the output effects of interest rate policy, since the induced macroeconomic variation triggers systematic, countercyclical fiscal policy rules.

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 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 results have implications for business cycle management and policy coordination, the redistributive effects of monetary policy, and optimal conduct for monetary policy. If systematic tax policy has little net inflationary effects, as in the estimated model, fiscal policy could alleviate even more aggressively the output and employment costs of monetary policy without impeding the central banks fight of inflation. Furthermore, distortionary labor income tax movements lead to redistributive effects that alter optimal monetary policy in HANK. These appear promising avenues for future research.

References

Alves, Felipe, Greg Kaplan, Benjamin Moll, and Giovanni L Violante (2020). "A further look at the propagation of monetary policy shocks in HANK". *Journal of Money, Credit and Banking 52* (S2), 521–559.

Ampudia, Miguel, Dimitris Georgarakos, Jiri Slacalek, Oreste Tristiani, Philip Vermeulen, and Giovanni L Violante (2018). *Monetary policy and household inequality.* 2170. ECB working paper.

Andreolli, Michele (2021). "Monetary policy and the maturity structure of public debt". *Available at SSRN 3921429.*

Angeletos, George-Marios, Fabrice Collard, and Harris Dellas (2020). "Business-cycle anatomy". *American Economic Review 110* (10), 3030–3070.

Aruoba, S Boragan and Thomas Drechsel (2023). "Identifying monetary policy shocks: A natural language approach". Tech. rep. Working Paper.

Auclert, Adrien, Matthew Rognlie, and Ludwig Straub (2018). "The intertemporal keynesian cross". Tech. rep. National Bureau of Economic Research.

——— (2020). "Micro jumps, macro humps: Monetary policy and business cycles in an estimated HANK model". Tech. rep. National Bureau of Economic Research.

Bauer, Michael D and Eric T Swanson (2023a). "A reassessment of monetary policy surprises and high-frequency identification". *NBER Macroeconomics Annual 37* (1), 87–155.

——— (2023b). "An alternative explanation for the "fed information effect"". *American Economic Review 113* (3), 664–700.

Bayer, Christian, Benjamin Born, and Ralph Luetticke (2023). "The liquidity channel of fiscal policy". *Journal of Monetary Economics 134*, 86–117.

——— (2024). "Shocks, Frictions, and Inequality in U.S. Business Cycles". *American Economic Review.*

Bayer, Christian and Ralph Luetticke (2020). "Solving discrete time heterogeneous agent models with aggregate risk and many idiosyncratic states by perturbation". *Quantitative Economics 11* (4), 1253–1288.

Bellifemine, Marco, Adrien Couturier, and Rustam Jamilov (2024). "Monetary Unions with Heterogeneous Fiscal Space".

Bernanke, Ben S and Ilian Mihov (1998). "Measuring monetary policy". *The quarterly journal of economics 113* (3), 869–902.

Bilbiie, Florin O, Giorgio Primiceri, and Andrea Tambalotti (2023). "Inequality and business cycles". Tech. rep. National Bureau of Economic Research.

Born, Benjamin and Johannes Pfeifer (2014). "Policy risk and the business cycle". *Journal of Monetary Economics 68*, 68–85.

Bouscasse, Paul and Seungki Hong (2023). "Monetary-Fiscal Interactions in the United States".

Breitenlechner, Max, Martin Geiger, and Mathias Klein (2024). "The fiscal channel of monetary policy". Tech. rep. Working Papers in Economics and Statistics.

Buda, Gergely, Vasco M Carvalho, Giancarlo Corsetti, João B Duarte, Stephen Hansen, Álvaro Ortiz, Tomasa Rodrigo, and José V Rodríguez Mora (2023). "Short and Variable lags". *Robert Schuman Centre for Advanced Studies Research Paper* (22).

Caldara, Dario and Edward Herbst (2019). "Monetary policy, real activity, and credit spreads: Evidence from Bayesian proxy SVARs". *American Economic Journal: Macroeconomics 11* (1), 157–92.

Caldara, Dario and Christophe Kamps (2017). "The analytics of SVARs: a unified framework to measure fiscal multipliers". *The Review of Economic Studies 84* (3), 1015–1040.

Calvo, Guillermo A (1983). "Staggered prices in a utility-maximizing framework". *Journal of monetary Economics 12* (3), 383–398.

Caravello, Tomás E, Alisdair McKay, and Christian K Wolf (2024). "Evaluating policy counterfactuals: A var-plus approach". Tech. rep. National Bureau of Economic Research.

Castaneda, Ana, Javier Dıaz-Giménez, and José-Victor Rıos-Rull (1998). "Exploring the income distribution business cycle dynamics". *Journal of Monetary economics 42* (1), 93–130.

Chari, Varadarajan V, Patrick J Kehoe, and Ellen R McGrattan (2009). "New Keynesian models: Not yet useful for policy analysis". *American Economic Journal: Macroeconomics 1* (1), 242–266.

Chetty, Raj, Adam Guren, Day Manoli, and Andrea Weber (2011). "Are micro and macro labor supply elasticities consistent? A review of evidence on the intensive and extensive margins". *American Economic Review 101* (3), 471–475.

Christiano, Lawrence, Martin Eichenbaum, and Sergio Rebelo (2011). "When is the government spending multiplier large?" *Journal of Political Economy 119* (1), 78–121.

Christiano, Lawrence J, Martin Eichenbaum, and Charles L Evans (2005). "Nominal rigidities and the dynamic effects of a shock to monetary policy". *Journal of political Economy 113* (1), 1–45.

Christiano, Lawrence J, Mathias Trabandt, and Karl Walentin (2010). "DSGE models for monetary policy analysis". *Handbook of monetary economics.* Vol. 3. Elsevier, 285–367.

Cloyne, James S, Òscar Jordà, and Alan M Taylor (2020). "Decomposing the fiscal multiplier". Tech. rep. National Bureau of Economic Research.

Cox, Lydia, Gernot J Müller, Ernesto Pasten, Raphael Schoenle, and Michael Weber (2024). "Big G". *Journal of Political Economy 132* (10), 3260–3297.

Feenberg, Daniel and Elisabeth Coutts (1993). "An introduction to the TAXSIM model". *Journal of Policy Analysis and management 12* (1), 189–194.

Fernández-Villaverde, Jesús, Juan F Rubio-Ramírez, Thomas J Sargent, and Mark W Watson (2007). “ABCs (and Ds) of understanding VARs”. *American economic review 97* (3), 1021–1026.

Fernández-Villaverde, Jesús, Juan Francisco Rubio-Ramírez, and Frank Schorfheide (2016). “Solution and estimation methods for DSGE models”. *Handbook of macroeconomics*. Vol. 2. Elsevier, 527–724.

Forni, Mario, Luca Gambetti, and Giovanni Ricco (2022). “External instrument SVAR analysis for noninvertible shocks”.

Gabaix, Xavier (2020). “A behavioral New Keynesian model”. *American Economic Review 110* (8), 2271–2327.

Galí, Jordi (2015). *Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework and its applications*. Princeton University Press.

Gertler, Mark and Peter Karadi (2015). “Monetary policy surprises, credit costs, and economic activity”. *American Economic Journal: Macroeconomics 7* (1), 44–76.

Gilchrist, Simon and Egon Zakrajšek (2012). “Credit spreads and business cycle fluctuations”. *American economic review 102* (4), 1692–1720.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory W Huffman (1988). “Investment, capacity utilization, and the real business cycle”. *The American Economic Review*, 402–417.

Guvenen, Fatih, Greg Kaplan, and Jae Song (2014). “How risky are recessions for top earners?” *American Economic Review 104* (5), 148–153.

Hack, Lukas, Klodiana Istrefi, and Matthias Meier (2023). “Identification of systematic monetary policy”.

Hamilton, James D (2018). “Why you should never use the Hodrick-Prescott filter”. *Review of Economics and Statistics 100* (5), 831–843.

Holm, Martin Blomhoff, Pascal Paul, and Andreas Tischbirek (2021). “The transmission of monetary policy under the microscope”. *Journal of Political Economy 129* (10), 2861–2904.

Jacobson, Margaret, Christian Matthes, and Todd B Walker (2022). “Inflation Measured Every Day Keeps Adverse Responses Away: Temporal Aggregation and Monetary Policy Transmission”.

Jarociński, Marek and Peter Karadi (2020). “Deconstructing monetary policy surprises—the role of information shocks”. *American Economic Journal: Macroeconomics 12* (2), 1–43.

Justiniano, Alejandro, Giorgio E Primiceri, and Andrea Tambalotti (2011). “Investment shocks and the relative price of investment”. *Review of Economic Dynamics 14* (1), 102–121.

Kaplan, Greg, Benjamin Moll, and Giovanni L Violante (2018). “Monetary policy according to HANK”. *American Economic Review 108* (3), 697–743.

Kaplan, Greg and Giovanni L Violante (2014). "A model of the consumption response to fiscal stimulus payments". *Econometrica 82* (4), 1199–1239.

——— (2022). "The marginal propensity to consume in heterogeneous agent models". *Annual Review of Economics 14* (1), 747–775.

Kaplan, Greg, Giovanni L Violante, and Justin Weidner (2014). "The Wealthy Hand-to-Mouth". *Brookings Papers on Economic Activity 45* (1), 77–138.

Kliem, Martin and Alexander Kriwoluzky (2014). "Toward a Taylor rule for fiscal policy". *Review of Economic Dynamics 17* (2), 294–302.

Leeper, Eric M, Michael Plante, and Nora Traum (2010). "Dynamics of fiscal financing in the United States". *Journal of Econometrics 156* (2), 304–321.

Li, Dake, Mikkel Plagborg-Møller, and Christian K Wolf (2022). "Local projections vs. vars: Lessons from thousands of dgps". Tech. rep. National Bureau of Economic Research.

Litterman, Robert B (1986). "Forecasting with Bayesian vector autoregressions—five years of experience". *Journal of Business & Economic Statistics 4* (1), 25–38.

Mangiante, Giacomo and Pascal Meichtry (2022). "On the Distributional Effects of Conventional Monetary Policy and Forward Guidance".

Marcellino, Massimiliano (1999). "Some consequences of temporal aggregation in empirical analysis". *Journal of Business & Economic Statistics 17* (1), 129–136.

McKay, Alisdair, Emi Nakamura, and Jón Steinsson (2016). "The power of forward guidance revisited". *American Economic Review 106* (10), 3133–3158.

McKay, Alisdair and Ricardo Reis (2016). "The role of automatic stabilizers in the US business cycle". *Econometrica 84* (1), 141–194.

McKay, Alisdair and Christian Wolf (2022). "Optimal policy rules in hank".

McKay, Alisdair and Christian K Wolf (2023). "What Can Time-Series Regressions Tell Us About Policy Counterfactuals?" *Econometrica 91* (5), 1695–1725.

Mertens, Karel and Morten O Ravn (2013). "The dynamic effects of personal and corporate income tax changes in the United States". *American economic review 103* (4), 1212–1247.

Miranda-Agrippino, Silvia and Giovanni Ricco (2021). "The transmission of monetary policy shocks". *American Economic Journal: Macroeconomics 13* (3), 74–107.

——— (2023). "Identification with external instruments in structural VARs". *Journal of Monetary Economics 135*, 1–19.

Nakamura, Emi and Jón Steinsson (2018). "High-frequency identification of monetary non-neutrality: the information effect". *The Quarterly Journal of Economics 133* (3), 1283–1330.

Perotti, Roberto (2005). "Estimating the effects of fiscal policy in OECD countries". *Available at SSRN 717561.*

Plagborg-Møller, Mikkel and Christian K Wolf (2021). "Local projections and VARs estimate the same impulse responses". *Econometrica 89* (2), 955–980.

——— (2022). "Instrumental variable identification of dynamic variance decompositions". *Journal of Political Economy 130* (8), 2164–2202.

Ramey, Valerie A (2016). "Macroeconomic shocks and their propagation". *Handbook of macroeconomics 2*, 71–162.

Romer, Christina D and David H Romer (2004). "A new measure of monetary shocks: Derivation and implications". *American Economic Review 94* (4), 1055–1084.

——— (2010). "The macroeconomic effects of tax changes: estimates based on a new measure of fiscal shocks". *American economic review 100* (3), 763–801.

Schmitt-Grohé, Stephanie and Martın Uribe (2004). "Solving dynamic general equilibrium models using a second-order approximation to the policy function". *Journal of economic dynamics and control 28* (4), 755–775.

Schmitt-Grohé, Stephanie and Martin Uribe (2012). "What's news in business cycles". *Econometrica 80* (6), 2733–2764.

Schorfheide, Frank and Dongho Song (2015). "Real-time forecasting with a mixed-frequency VAR". *Journal of Business & Economic Statistics 33* (3), 366–380.

Sims, Christopher A and Tao Zha (1998). "Bayesian methods for dynamic multivariate models". *International Economic Review*, 949–968.

Slacalek, Jiri, Oreste Tristani, and Giovanni L Violante (2020). "Household balance sheet channels of monetary policy: A back of the envelope calculation for the euro area". *Journal of Economic Dynamics and Control 115*, 103879.

Smets, Frank and Rafael Wouters (2007). "Shocks and frictions in US business cycles: A Bayesian DSGE approach". *American economic review 97* (3), 586–606.

Sterk, Vincent and Silvana Tenreyro (2018). "The transmission of monetary policy through redistributions and durable purchases". *Journal of Monetary Economics 99*, 124–137.

Storesletten, Kjetil, Chris I Telmer, and Amir Yaron (2004). "Cyclical dynamics in idiosyncratic labor market risk". *Journal of Political Economy 112* (3), 695–717.

Tauchen, George (1986). "Finite state markov-chain approximations to univariate and vector autoregressions". *Economics letters 20* (2), 177–181.

Taylor, John B (1993). "Discretion versus policy rules in practice". *Carnegie-Rochester conference series on public policy.* Vol. 39. Elsevier, 195–214.

Treasury, US (2023). *Financial Report of the United States Government.* 16 February, Washington, https://fiscaldata.treasury.gov/static-data/published-reports/frusg/FRUSG_2022.pdf.

Wolf, Christian K (2020). "Svar (mis) identification and the real effects of monetary policy shocks". *American Economic Journal: Macroeconomics 12* (4), 1–32.

Woodford, Michael (2011). “Simple analytics of the government expenditure multiplier”. *American Economic Journal: Macroeconomics 3* (1), 1–35.

Wu, Jing Cynthia and Fan Dora Xia (2016). “Measuring the macroeconomic impact of monetary policy at the zero lower bound”. *Journal of Money, Credit and Banking 48* (2-3), 253–291.

Appendix A Detailed data description

A.1 Data for VAR analysis

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	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 value of debt	Real value of Federal Debt Held by the Public, per capita	Divided by the CPI and population, enters the VAR in log x 100	FRED (FYGFDPUN)
Government spending	Real general government consumption and investment, per capita	Divided by population, enters the VAR in log x 100	FRED (B822RA3Q086SBEA)
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). Enters the VAR in levels.	FRED
Real market value of debt	Per capita	Divded by CPI and population, enters the VAR in log x 100	FRED (MVGFD027MNFRBDAL)
Interest payment	Real federal government interest payments, per capita	Divded by CPI and population, enters the VAR in log x 100	FRED (A091RC1Q027SBEA)
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, enters the VAR in log x 100	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, enters the VAR in log x 100	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, enters the VAR in log x 100	FRED (FGRECPT)
Cycl. adj. tax revenues (CBO)	Real federal tax revenues, cyclically adjusted	Divded by population, enters the VAR in log x 100	Congressional Budget Office
Avg. tax rate (taxsim)	Average effective income tax rate	See text for a description. Enters the VAR in levels.	TAXSIM, NBER
Output gap	Cyclical component of Real per-capita log x 100 GDP	Cyclical component is computed using the Hamilton (2018) filter. GDP (GDPC1) divded by population.	FRED
Monetary policy proxy	High-frequency yield surprise	First principle component of several high-frequency variables around FOMC announcements. Enters the VAR in levels.	Bauer and Swanson (2023a)

[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 mnenomincs 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 output ratio**: Government debt held by the public (FYGFDPUN) divided by annual GDP.

3. **Top 10% wealth share**: World Inequality Database: https://wid.world/country/usa/

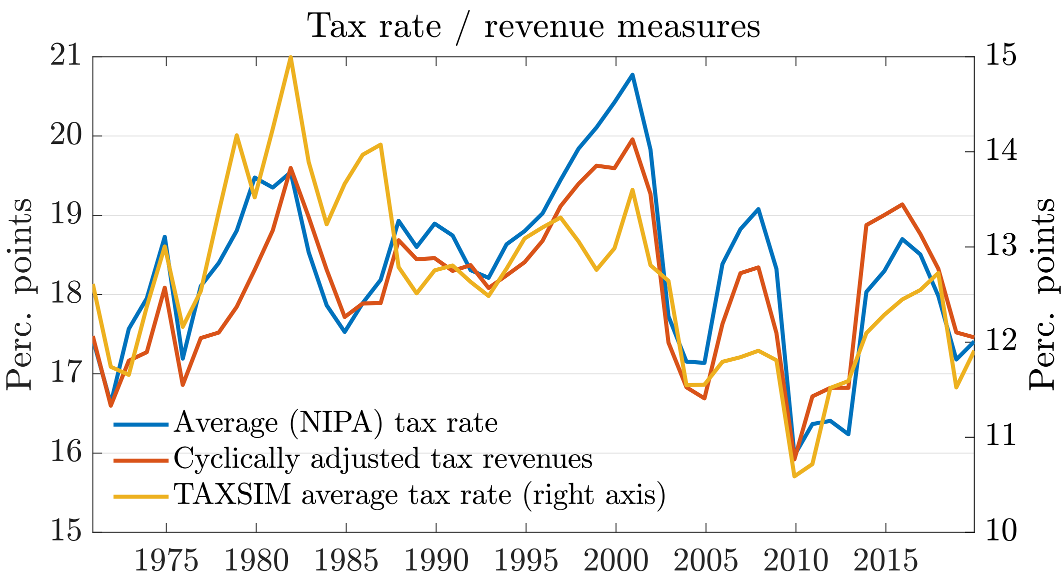
4. **Fraction of poor hand-to-mouth households**: Kaplan, Violante, and Weidner (2014) report based on the Survey of Consumer Finances, waves 1989 – 2010, that 17% of households are poor hand-to-mouth based on the definition that they would be unable to come up with 2000$ if a sudden shock would require such a payment. This definition corresponds well to the lowest liquid asset gridpoint in the model.

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

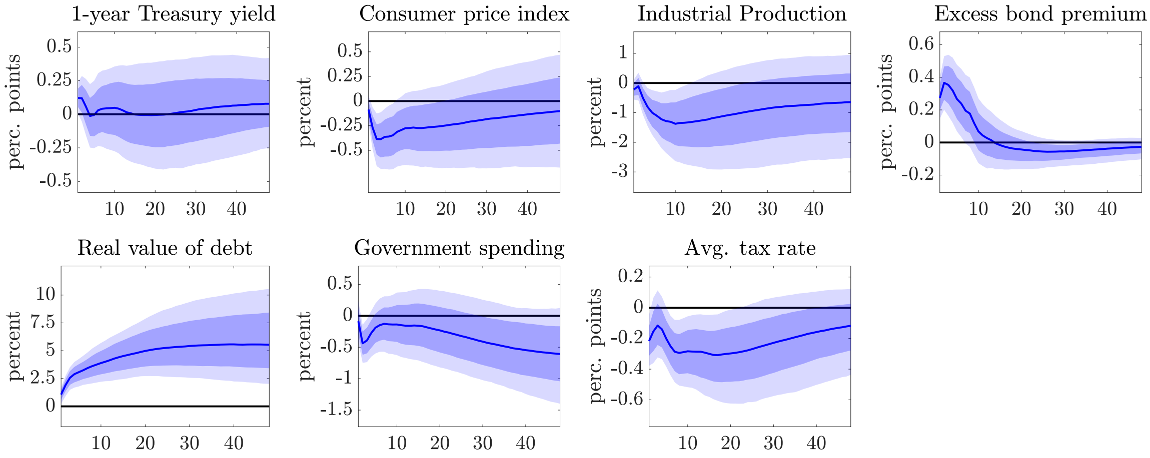
Figure A.1: Changes in the tax code and comparison of tax rate measures



Appendix B Further SVAR results

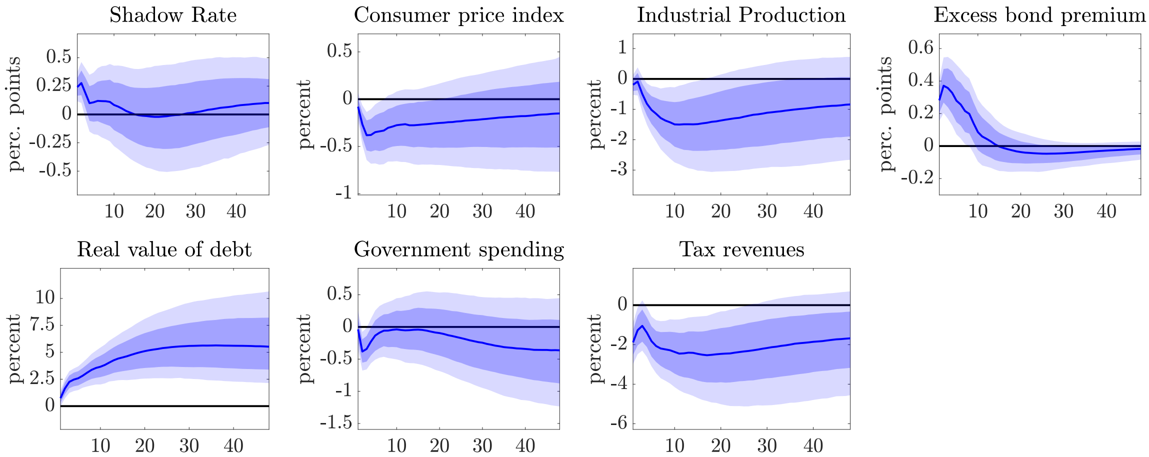
B.1 Additional results to monetary shocks

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



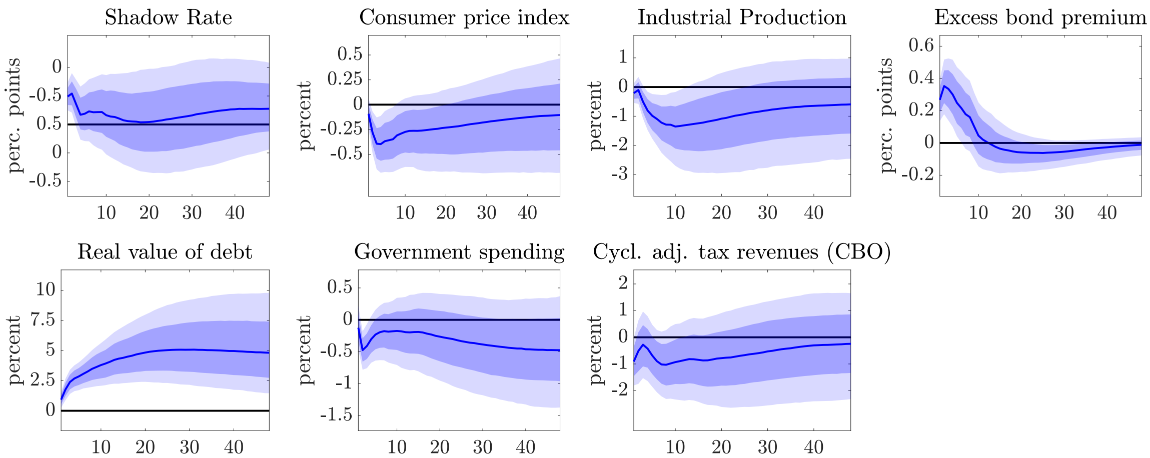
Notes: Impulse response functions to a shock of the same size that increases the shadow rate by 25bps in the baseline results (1). Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.2: 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.3: MF-BVAR: Robustness exercise with cyclically adjusted federal tax revenues

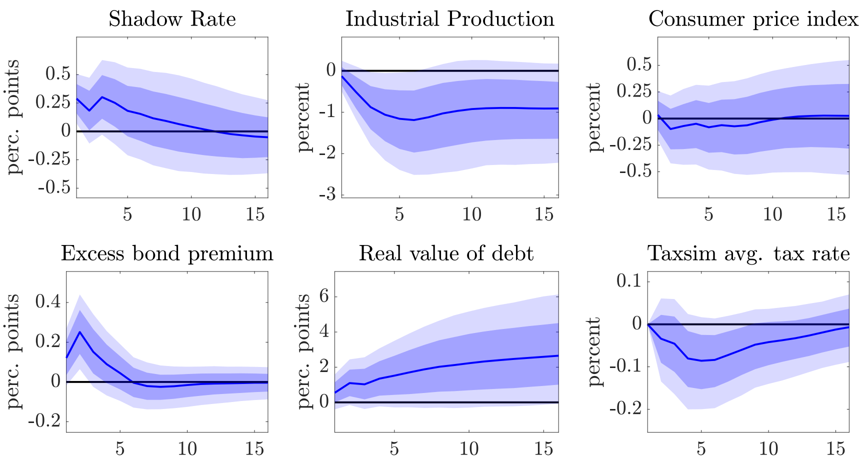


Notes: Impulse response functions to a 25bps shock. Point-wise posterior means along with 68% and 90% point-wise credible sets. Horizon in months.

Figure B.4: 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.

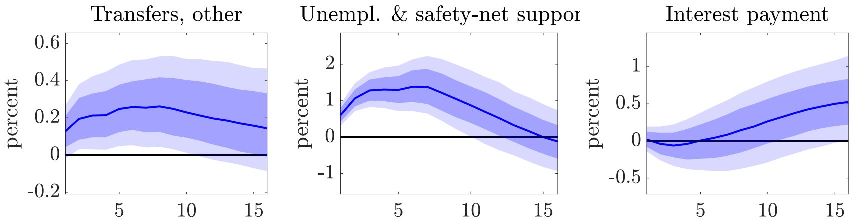
Figure B.5: MF-BVAR: quarterly - annual model, zero restriction on contemporaneous tax response



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.6: MF-BVAR: Transfer and interest payment responses to the MBC shock



Notes: Both 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 ontinuation 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 $\{x_{a,t}^*, x_{n,t}^*, b_{a,t}^*, b_{n,t}^*, k_t^*\}$.

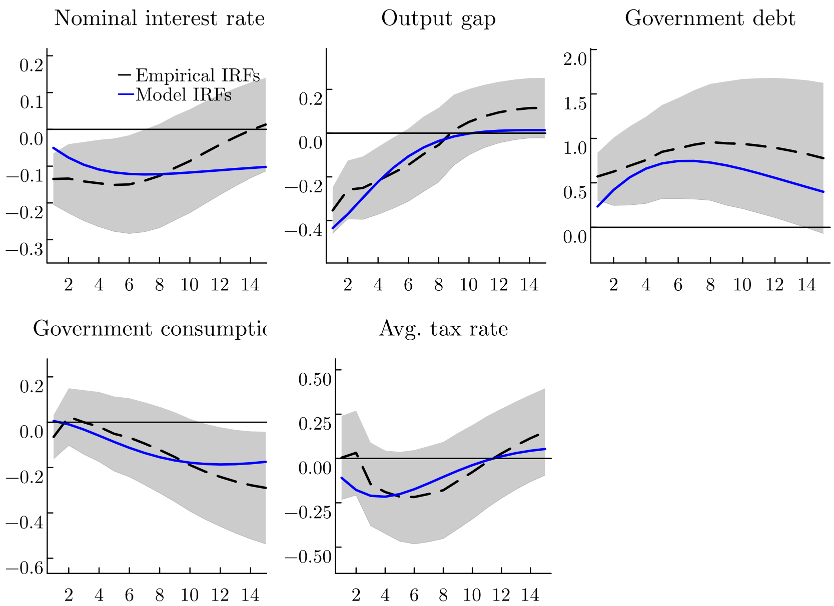
2. Distributions of wealth and income evolve according to households' policy functions.

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 HANK estimation results

Figure D.1: 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.1: Prior and Posterior Distributions of Estimated Parameters, demand shock

Parameter	Prior Distribution	Prior Mean	Prior Std. dev.	Posterior: Posterior Mean MBC shock
		Frictions		
δ_s	Gamma	5.00	2.00	4.24
ϕ	Gamma	4.00	2.00	4.06
κ	Gamma	0.1	0.02	0.0105
κ_w	Gamma	0.1	0.02	0.097
		Taylor rule		
ρ_R	Beta	0.85	0.1	0.97
θ_π	Normal	2.0	0.3	1.72
θ_Y	Normal	0.125	0.05	0.29
		Exogenous demand shock process		
ρ_A	Beta	0.5	0.2	0.94
σ_A	Inv. Gamma	0.05	0.02	0.038
		Fiscal rules		
ρ_G	Beta	0.5	0.2	0.83
$-\gamma_B^G$	Gamma	0.5	0.25	0.32
γ_Y^G	Normal	0.0	1.0	-0.07
ρ_τ	Beta	0.5	0.2	0.84
γ_B^τ	Gamma	0.5	0.25	0.18
γ_Y^τ	Normal	0.0	1.0	1.56