Why the Federal Reserve Cuts Rates when Public Debt Rises*

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Abstract

We document a new fact: conditional on inflation and output, the Federal Reserve tends to lower its policy rate when the U.S. public debt-to-GDP ratio rises. To explain this pattern, we develop and estimate a New Keynesian model with shocks to households' demand for public debt. These shocks generate a negative comovement between public debt and the natural rate of interest, defined as the real rate that would prevail in the flexible-price economy. Assuming that the Federal Reserve adjusts its policy rate in line with the natural rate, this mechanism rationalizes the negative relationship between debt and the policy rate. We show that shocks to the demand for public debt are a key driver of business-cycle fluctuations and that policy rules responding to the natural rate reduce the volatility of inflation and output relative to standard rules. We further construct a debt-informed measure of the natural rate using a time-varying parameter vector autoregression model. Once this measure is included in the policy rule, an increase in the debt-to-GDP ratio no longer reduces the federal funds rate, consistent with the mechanism highlighted by the model.

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1 Introduction

Does the Federal Reserve respond to fiscal conditions, particularly the level of public debt, when setting interest rates? The prevailing view in macroeconomics holds that fiscal policy influences monetary decisions only indirectly, through its effects on inflation and output. Under this interpretation, public debt should not directly affect the conduct of monetary policy. Yet the Federal Reserve may face incentives or political pressure to lower interest rates when debt increases, easing the government's financing burden. This possibility has gained renewed attention as the independence of the Federal Reserve has come into question.

We inform this debate with a new fact: conditional on inflation and output, the Federal Reserve tends to lower its policy rate when the U.S. debt-to-GDP ratio rises. We argue that this behavior does not reflect political pressure. Instead, the Federal Reserve responds to the information that debt conveys about the natural rate of interest, the real rate that would prevail in a frictionless economy.

We provide theoretical motivation, empirical evidence, and quantitative results supporting this interpretation. We begin by constructing a novel New Keynesian model in which a higher demand for public debt lowers the natural rate. Under the assumption that the Federal Reserve sets the nominal rate in line with the natural rate, the policy rate also declines, rationalizing the negative relationship observed in the data. Empirically, we construct a new debt-informed measure of the natural rate. Once movements in this measure are accounted for, the negative relationship between debt and the policy rate disappears, consistent with the model's predictions. Finally, we develop and estimate a quantitative DSGE model that reproduces the joint dynamics of public debt, the nominal rate, and the natural rate. These results support our view that the Federal Reserve responds not to debt itself, but to the information it conveys about the natural rate.

The paper begins by documenting the key fact: conditional on inflation and output, the Federal Reserve tends to lower its policy rate when the U.S. public debt-to-GDP ratio rises. To test this, we augment the standard Taylor rule—which relates interest rates to inflation and the output gap[1]—by including the debt-to-GDP ratio. This approach allows us to directly test whether public debt influences monetary policy beyond the effects of inflation and real activity.

In the Taylor rule, the error term may capture monetary policy shocks that are correlated with inflation, output, and debt, raising potential endogeneity concerns. We address this issue by estimating the equation with the generalized method of moments using different

[1] The Taylor rule is a widely used specification in the monetary policy literature. See Clarida, Gali, and Gertler (2000), Orphanides (2001), Mavroeidis (2010), Bauer, Pflueger, and Sunderam (2024), and Bocola et al. (2024).

instrument sets. In all specifications, the coefficient on debt is negative and statistically significant: a 10-percentage-point increase in the debt-to-GDP ratio is associated with a reduction of about 70 basis points in the federal funds rate. By comparison, a 1-percentage-point increase in inflation raises the policy rate by roughly 130 basis points.[2]

A natural interpretation of this finding is that the fiscal authority pressures the Federal Reserve to lower the policy rate to ease the burden of higher public debt. However, this view is difficult to reconcile with the U.S. experience over our sample period, 1979:Q3–2019:Q4, during which the Federal Reserve maintained a high degree of independence. To assess this possibility more directly, we augment the Taylor rule with debt by adding measures of political pressure. First, we include the number of direct interactions between the U.S. president and the Federal Reserve chair, constructed by Drechsel (2024). Second, we add the number of quarters remaining until the next presidential or midterm election, under the idea that proximity to elections increases incentives for the incumbent administration to favor easier monetary conditions. In both cases, the results are unchanged: the coefficient on the debt-to-GDP ratio remains negative, statistically significant, and similar in magnitude, indicating that the negative relationship between debt and the policy rate cannot be explained by political influence.

We next examine alternative explanations for why the Federal Reserve lowers its policy rate when public debt rises. One possibility is that this pattern reflects information contained in debt about future economic conditions. To test this, we extend the benchmark rule by including realized or expected values of future inflation and output. Public debt may also convey information about financial conditions, so we include variables capturing credit and risk spreads, stock-market returns, and financial volatility measured by the CBOE Volatility Index. Across all these extensions, the coefficient on the debt-to-GDP ratio remains negative and statistically significant.

The finding that higher public debt leads the Federal Reserve to lower its policy rate is difficult to reconcile with the standard New Keynesian model (Woodford, 2003; Galí, 2015). In this framework, changes in public debt arise from higher deficits—through increased spending or lower taxes—that raise output and inflation, prompting the monetary authority to increase the policy rate. The model thus predicts a positive comovement between debt and the nominal interest rate. Furthermore, conditional on inflation and output, higher debt does not affect the policy rate, whereas our evidence shows a negative effect.

To explain our empirical findings, we extend the textbook New Keynesian model in

[2]Following standard practice in the Taylor rule literature, all reported coefficients should be interpreted as long-run estimates that account for the gradual adjustment of the policy rate. They capture the total response of the policy rate after the adjustment process is complete, rather than the impact effect.

four ways. First, households derive utility from holding government bonds, which makes the interest rate depend on public debt and breaks Ricardian equivalence, making fiscal behavior central to equilibrium outcomes. Second, we introduce shocks to the utility value of bonds that drive fluctuations in the demand for public debt. These *liquidity* or *safety* shocks capture exogenous shifts in households' preference for holding safe and liquid assets—public debt—when the perceived value of safety rises or precautionary motives strengthen.[3] Third, fiscal revenues respond not only to output and debt but also to the interest rate. Finally, monetary policy follows a Taylor rule that targets inflation and the output gap and also responds to movements in the natural rate.[4]

In the model, a positive liquidity shock increases households' preference for holding government bonds. Higher demand lowers the cost of debt issuance, inducing the fiscal authority to issue more bonds and households to raise saving, which reduces consumption. As a result, output and the natural rate of interest decline. Since the monetary authority sets the policy rate in line with the natural rate, it reduces the nominal interest rate. This mechanism explains why the Federal Reserve reduces its policy rate when public debt rises: it reacts not to debt itself but to the information it conveys about the natural rate.

We then test the model's mechanism by examining whether the effect of debt on the policy rate disappears once the natural rate is included in the policy rule. To do so, we incorporate existing estimates of the natural rate from Laubach and Williams (2003), Lubik and Matthes (2015), and Holston, Laubach, and Williams (2017) into our benchmark Taylor rule with public debt. Across all cases, the coefficient on debt remains negative and statistically significant. In our preferred specification, which uses the estimates of Lubik and Matthes (2015), the coefficient on debt roughly halves in magnitude, while the coefficient on the natural rate is positive and significant. These results suggest that the Federal Reserve adjusts the policy rate in line with the natural rate. However, existing measures cannot fully capture the effect of public debt on monetary policy because they omit the information about the natural rate contained in public debt.[5]

To address this limitation, we construct a debt-informed measure of the natural rate. Following Lubik and Matthes (2015), we estimate a time-varying-parameter vector autoregression that includes, in addition to the real interest rate, GDP growth, and CPI inflation, the debt-to-GDP ratio. We define the natural rate as the five-year-ahead forecast of the real

[3]For example, precautionary saving motives may increase when labor market conditions become more uncertain or when the economy is perceived as riskier.

[4]Remark that the natural rate of interest refers to the equilibrium real interest rate in the flexible-price economy.

[5]Laubach and Williams (2003) note that fiscal policy may affect the natural rate but do not model this channel explicitly.

interest rate, based on the idea that shocks still affect the economy but nominal frictions have vanished. When this measure is included in our benchmark Taylor rule, the coefficient on the debt-to-GDP ratio becomes insignificant, while that on the natural rate is positive and statistically significant. The estimated coefficient on the natural rate is about 1.3, indicating a slightly more than one-for-one response of the nominal rate. Excluding debt from the specification leaves this estimate virtually unchanged. These results support the view that debt influences policy rates only through the information it conveys about the natural rate.

We next evaluate the quantitative importance of the mechanism by which liquidity shocks affect public debt, the natural rate, and the policy rate. To this end, we develop and estimate a New Keynesian DSGE model that extends Justiniano, Primiceri, and Tambalotti (2010)'s framework. As in their setup, the model features nominal wage and price rigidity, consumption habits, investment adjustment costs, capital accumulation, and variable capital utilization. It also includes the elements introduced above: households derive utility from holding government bonds, fiscal revenues respond to output, debt, and the interest rate, and monetary policy follows a Taylor rule augmented with the natural rate.

We estimate the model using standard Bayesian methods. The variance decomposition shows that shocks to households' demand for public debt account for roughly 40 percent of the fluctuations in output, public debt, the nominal interest rate, the natural rate, and hours worked, making them a major driver of business-cycle dynamics. Conditional on a liquidity shock, debt comoves negatively with both the natural rate and the nominal rate, consistent with the view that public debt contains information about movements in the natural rate.

Finally, we conduct two simulation exercises to further assess the model's implications. First, we generate data from the estimated model under a Taylor rule that responds to the natural rate but not to public debt. Using these simulated data, we then estimate a Taylor rule that includes public debt instead of the natural rate, as in our empirical analysis. In these regressions, the coefficient on public debt is negative and statistically significant, confirming that in the model the natural rate and public debt comove negatively and that debt contains information about the natural rate. This result mirrors our empirical finding that the Federal Reserve does not respond to debt itself but to the information it conveys about the natural rate. Second, we simulate the economy under two alternative policy rules—one that responds to the natural rate and one that does not. Inflation and the output gap are less volatile when the rule incorporates the natural rate, indicating that monetary policy stabilizes the economy more effectively when it tracks movements in the natural rate.

To conclude, our empirical finding that the Federal Reserve lowers the policy rate when public debt rises might appear to reflect an accommodative stance toward fiscal policy. We demonstrate instead that public debt conveys information about the natural rate of interest, and that the Federal Reserve's response to debt operates through this channel.

Related literature. We make several contributions to the literature. First, we extend the literature estimating the natural rate of interest (Laubach and Williams, 2003; Lubik and Matthes, 2015; Holston, Laubach, and Williams, 2017; Del Negro et al., 2017; Johannsen and Mertens, 2021), which abstracts from public debt. We show that movements in public debt affect the natural rate and construct a debt-informed measure that incorporates this information.

Second, our work relates to studies of fiscal–monetary interactions (Sargent and Wallace, 1981; Leeper, 1991; Christiano, Eichenbaum, and Rebelo, 2011; Leeper, Traum, and Walker, 2017; Bianchi, Faccini, and Melosi, 2023; Smets and Wouters, 2024). Most existing analyses focus on interactions driven by government spending shocks, whereas we emphasize shocks to households' demand for public debt. This perspective explains the negative comovement between nominal interest rates and public debt.

Third, we build on the literature that embeds bonds in household utility (Campbell et al., 2017; Kaplan and Violante, 2018; Hagedorn, 2018; Michaillat and Saez, 2021). We depart from the standard assumption of zero net bond supply and instead allow bonds—interpreted as public debt—to fluctuate over the business cycle. We also introduce shocks to the utility of bonds, which capture shifts in the demand for safe assets and admit several interpretations. They microfound the "risk-premium" shock of Smets and Wouters (2007) when debt supply is zero (Fisher, 2015); appear as spread or flight-to-safety shocks in the international literature (Eichenbaum, Johannsen, and Rebelo, 2021; Kekre and Lenel, 2024); and can be viewed as increases in idiosyncratic risk (Aiyagari, 1994; Bayer et al., 2019) or in the riskiness of capital returns (Li and Merkel, 2025). In each case, households shift resources toward government bonds and away from capital, reducing investment and consumption and generating a recession.

Fourth, our framework is closely connected to the literature on analytically tractable heterogeneous-agent New Keynesian (HANK) models. Kaplan and Violante (2018), Auclert, Rognlie, and Straub (2024), Auclert, Rognlie, and Straub (2025), and Wolf (2025) show that bond-in-utility models reproduce key aggregate behavior of HANK economies while remaining tractable.[6] Our approach is particularly close to Angeletos, Lian, and Wolf (2024a,b), who construct HANK models without explicit heterogeneity. In their setting, debt affects household behavior because agents are finitely lived; in ours, because bonds provide utility. We develop and estimate, rather than calibrate, a quantitative model that embeds

[6] Auclert, Rognlie, and Straub (2024, 2025) show that adding hand-to-mouth households improves the match to the intertemporal marginal propensity to consume out of labor income in HANK models.

this mechanism together with standard DSGE frictions.

Finally, our analysis is related to Summers and Rachel (2019), Campos et al. (2024), and Nuño (2025), who examine how variations in public debt affect the natural rate of interest. These papers document a positive relationship between public debt and the natural rate. Our work differs in two key respects. First, they define the natural rate as the steady-state interest rate, whereas we follow the New Keynesian and DSGE tradition in defining it as the equilibrium rate in the flexible-price economy (e.g. Woodford, 2003; Smets and Wouters, 2007; Justiniano and Primiceri, 2008; Justiniano, Primiceri, and Tambalotti, 2013; Galí, 2015). Second, their focus is on a permanent debt increase driven by higher government purchases, while we study debt fluctuations at business-cycle frequencies generated by shocks to households' demand for public debt.

Outline. The paper is organized as follows. Section 2 documents our empirical finding that the Federal Reserve lowers the policy rate when public debt increases. Section 3 presents a stylized New Keynesian model that explains this empirical finding. Section 4 constructs a debt-informed measure of the natural rate and shows that it explains the observed relationship between debt and the policy rate. Section 5 estimates and discusses the results of our quantitative New Keynesian DSGE model. Section 6 concludes.

2 Empirical Strategy and Results

In this section, we show that the Federal Reserve adjusts its policy rate in response not only to inflation and output but also to the public debt-to-GDP ratio. We estimate a standard Taylor rule augmented with public debt to establish this result.

Section 2.1 presents the benchmark specification. Section 2.1.1 confirms the robustness of the result across alternative measures of inflation and different sample periods. Section 2.1.2 addresses concerns about low-frequency trends using complementary empirical strategies. Finally, Section 2.2 rules out alternative explanations, such as the possibility that public debt contains information about future economic conditions.

2.1 Main empirical result

Following Taylor (1993), the Taylor rule provides a benchmark for how the policy rate responds to movements in inflation and the output gap. We augment this specification by including the public debt-to-GDP ratio:

$$r_t = c + \alpha\pi_t + \beta y_t + \gamma d_t + \rho_1 r_{t-1} + \rho_2 r_{t-2} + u_t \tag{1}$$

where r_t is the yearly federal funds rate, π_t is inflation, y_t is the output gap, d_t is the public debt-to-GDP ratio, and u_t is the error term, interpreted as the monetary policy shock. We focus on estimating the coefficient γ, which captures the response of the policy rate to movements in public debt: A negative value of γ indicates that the Federal Reserve lowers the policy rate when the debt-to-GDP ratio rises. For interpretability, we rescale d_t so that γ measures the effect of a ten–percentage–point increase in the debt-to-GDP ratio.

A challenge in estimating equation (1) is potential endogeneity: inflation, the output gap and debt may be correlated with the residual, interpreted as the monetary policy shock. We first estimate equation (1) by ordinary least squares (OLS). Monetary policy shocks, u_t, account for only a small share of business-cycle fluctuations;[7] it follows that any bias resulting from OLS estimation is limited (Carvalho, Nechio, and Tristao, 2021). We then employ two instrumental-variable strategies. Following Clarida, Gali, and Gertler (2000), we estimate the equation by generalized method of moments (GMM) using lagged variables as instruments, which are predetermined relative to policy shocks. Following Barnichon and Mesters (2020), we also use macroeconomic shocks orthogonal to monetary policy shocks as instruments—specifically, the business-cycle shock of Angeletos, Collard, and Dellas (2020)[8] and the excess bond-premium shock of Gilchrist and Zakrajšek (2012).[9] These shocks are orthogonal to monetary policy shocks[10] and generate variation at business-cycle frequencies in inflation, the output gap, and public debt, making them suitable instruments.

We estimate equation (1) using quarterly data from 1979:Q3 to 2019:Q4. The sample includes the federal funds rate, CPI inflation, the CBO output gap, and the market value of gross federal debt over GDP. Between 2009:Q1 and 2015:Q4, we replace the federal funds rate with the shadow rate of Wu and Xia (2016) to capture the stance of monetary policy during the zero lower bound period. Table 1 reports the results. Column (1) presents OLS estimates. Column (2) reports GMM estimates using four lags of the independent variables, commodity price inflation, money growth, and the spread between the long-term bond rate and the three-month Treasury bill as instruments.[11] Column (3) uses GMM with four lags

[7]This is well documented in the DSGE literature; see Smets and Wouters (2007), Justiniano, Primiceri, and Tambalotti (2010), Justiniano, Primiceri, and Tambalotti (2011), Christiano, Motto, and Rostagno (2014), and Smets and Wouters (2024).

[8]Identified with a max-share approach in a VAR, which finds the linear combination of structural shocks that maximizes unemployment fluctuations over the business cycle; see Barsky and Sims (2011) and Francis et al. (2014).

[9]Identified using a Cholesky decomposition in a VAR.

[10]The shock of Angeletos, Collard, and Dellas (2020) is not perfectly orthogonal to monetary policy shocks, since it is a linear combination of all structural shocks. However, as noted by Carvalho, Nechio, and Tristao (2021), monetary policy shocks explain little of business-cycle variation and therefore receive negligible weight in this linear combination.

[11]These are the same instruments as in Clarida, Gali, and Gertler (2000).

of the independent variables and lags five through twenty of the business-cycle shock of Angeletos, Collard, and Dellas (2020), while Column (4) replaces this shock with the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) employs only lagged structural shocks as instruments: the business-cycle shock, the excess bond-premium shock, the oil news shocks of Känzig (2021), and the fiscal shocks of Ramey (2016). All coefficients are divided by $1-\rho \equiv 1-\rho_1-\rho_2$, so that the reported parameters correspond to $\pi_t^{cpi} \equiv \frac{\alpha}{1-\rho}$, $y_t^* \equiv \frac{\beta}{1-\rho}$, $d_t \equiv \frac{\gamma}{1-\rho}$, and $\rho \equiv \rho_1+\rho_2$. This scaling follows standard practice in the literature and allows interpretation of the coefficients as long-run effects. Standard errors are computed using Newey and West (1987) corrections with four lags.

Table 1: Taylor rule with public debt-to-GDP ratio

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	1.17***	1.11***	1.30***	1.20***	1.18***
	0.251	0.220	0.171	0.220	0.122
y_t	0.60***	0.73***	0.84***	0.83***	0.44***
	0.195	0.172	0.162	0.163	0.086
d_t	-0.74***	-0.80***	-0.55***	-0.59***	-0.97***
	0.219	0.179	0.161	0.178	0.083
ρ	0.68***	0.76***	0.72***	0.78***	0.61***
	0.106	0.051	0.032	0.0441	0.041
N	162	159	162	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1+\rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table 1 reveals a consistent pattern across all specifications: the coefficient on the debt-to-GDP ratio is negative and statistically significant. On average, a ten–percentage–point increase in the debt-to-GDP ratio lowers the federal funds rate by about 70 basis points, conditional on inflation and the output gap. The estimated coefficients are also remarkably similar across columns, suggesting that endogeneity is limited and that public debt helps explain interest rate decisions. Consistent with the literature, the coefficients on inflation and the output gap are positive and statistically significant. Their magnitudes are in line with standard Taylor rule estimates, with the inflation coefficient around 1.5 and the output-gap coefficient around 0.6.

2.1.1 Robustness of the main specification

In this section, we assess the robustness of the results reported in Table 1. All tables discussed below are constructed in the same way as Table 1.

In Table 1, inflation is measured using the CPI. The results are similar when inflation is measured using the GDP deflator or the PCE price index (Table A.1 and Table A.2, respectively). In Table 1, we replace the federal funds rate with the shadow rate of Wu and Xia (2016) for the period from 2009:Q1 to 2015:Q4. Table A.3 shows that the results are similar when the federal funds rate is used for the entire sample period. The only difference is that the estimated coefficients on inflation, the output gap, and the debt-to-GDP ratio are smaller in magnitude. This reflects the fact that the federal funds rate was less volatile than the shadow rate during the zero lower bound period.

To further corroborate our results, we shorten the sample period and end the estimation in 2011:Q3, when the zero lower bound became binding for the federal funds rate. Table A.4 reports the results, showing again that the coefficient on the debt-to-GDP ratio is negative and statistically significant. The estimated coefficient is larger than in Table 1, likely because the debt-to-GDP ratio was relatively stable during the period from 2011 to 2019.

A possible concern is that, in our baseline specification, we divide public debt at time t by GDP at time t, and the estimated coefficient might capture contemporaneous movements in GDP rather than debt. This should not pose a problem, as we already control for the output gap. Nevertheless, to further corroborate our results, we reconstruct the debt-to-GDP ratio by dividing public debt by GDP at time $t-1$, ensuring that the Federal Reserve's response is not driven by contemporaneous changes in GDP. Table A.5 shows that the results remain robust. Similarly, Table A.6 reports estimates obtained when the debt-to-GDP ratio is constructed using potential GDP at time t instead of actual GDP, leading to the same conclusion.

Finally, following Clarida, Gali, and Gertler (2000), we estimate the Taylor rule using realized variables at time $t+1$, under the assumption that the Federal Reserve is forward looking and responds to expected rather than contemporaneous conditions. Accordingly, we replace inflation and the output gap in equation (1) with their realized values at time $t+1$. Table A.7 confirms that the coefficient on the debt-to-GDP ratio remains negative and statistically significant.

In summary, across all robustness exercises, the estimated coefficient on public debt remains negative, statistically significant, and similar in magnitude to the benchmark specification. These results confirm our finding that the Federal Reserve lowers the policy rate when the debt-to-GDP ratio rises.

2.1.2 Controlling for low-frequency variation

Another potential concern is that our results may be driven by low-frequency comovements in debt, inflation, output, and interest rates rather than higher-frequency fluctuations. In other words, trends in the data could underlie the estimated relationships. As noted by Granger and Newbold (1974), if this were the case, the regression residuals should exhibit serial correlation. To test for this possibility, Table A.8 reports the results of the Cumby and Huizinga (1992) serial correlation test. Each column corresponds to the respective specification in Table 1, and each row reports the test statistic under the null that all autocorrelation coefficients up to the given lag are zero. We find no evidence of serial correlation in the residuals, suggesting that our results are not driven by low-frequency trends.

We further address time-trend concerns in three ways. First, we estimate the Taylor rule using detrended series for inflation, output, interest rates, and the debt-to-GDP ratio. Table A.9 reports the results, where all variables are standardized to facilitate interpretation: each coefficient measures how many standard deviations the filtered federal funds rate changes in response to a one-standard-deviation change in the corresponding independent variable. As in Table 1, all coefficients are divided by $1-\rho_1-\rho_2 \equiv 1-\rho$, allowing interpretation in terms of long-run effects. Column (1) presents the OLS estimates without detrending for comparison. Columns (2) and (4) report OLS estimates using different detrending methods, while Columns (3) and (5) use lagged macroeconomic shocks—those employed in the last column of Table 1—as instruments. We use these shocks as instruments because they exhibit no trend and therefore need not be detrended. Columns (2) and (3) apply the one-sided Hodrick and Prescott (1997) filter, and Columns (4) and (5) apply the Hamilton (2018) filter.

Table A.9 confirms our main finding: the coefficient on the debt-to-GDP ratio is negative and statistically significant. The coefficients on debt obtained from detrended regressions are slightly smaller than those from the level specification (column 1) but remain significant, confirming that our benchmark results are not driven by trend effects. On average, a one–standard–deviation increase in the detrended debt-to-GDP ratio reduces the federal funds rate by about 0.25 standard deviations. The coefficient on inflation is positive and statistically significant, with a slightly larger magnitude of about 0.45, indicating that debt has an economically meaningful effect on monetary policy decisions. The coefficient on the output gap is also positive, as expected, though not always statistically significant, with a magnitude around 0.3—very close to that of debt.

In Table A.9, we detrend all variables and include lagged interest rates as controls. However, once the data are detrended, it is also consistent to exclude lagged interest rates, since they no longer convey independent information about persistent dynamics. We therefore re-estimate the same specification without lagged interest rates, again standardizing all variables for interpretability. Table A.10 reports the results, which display the same pattern as Table A.9: the coefficient on the debt-to-GDP ratio remains negative and statistically significant, with a magnitude similar to that of inflation.

The second approach to address trend concerns relies on using, as instruments, only macroeconomic shocks that are orthogonal to monetary policy shocks. Because these shocks exhibit no trend, the fitted values from the first-stage regression cannot load on low-frequency movements. Consequently, in the second stage of the GMM estimation, the instrumented independent variables also contain no trend component, ensuring that the results are not driven by trends. This consideration also motivates the inclusion of column (5) in Table 1. Figure A.1 plots the first-stage fitted values of the debt-to-GDP ratio from that specification, illustrating that the instrumented series displays no trend—further confirming that our results are not driven by low-frequency variation.

The third method to address low-frequency concerns employs the system-projections instrumental-variables (SP-IV) method of Lewis and Mertens (2022), which estimates the Taylor rule in the impulse-response-function space, where variables do not exhibit trends.[12] We again use the same macroeconomic shocks as in column (5) of Table 1 as instruments, together with one to six lags of these shocks as controls. Table A.11 reports the results, showing once more that the coefficient on the debt-to-GDP ratio is negative and statistically significant.

Taken together, the evidence from detrended regressions, orthogonal-instrument specifications, and the SP-IV estimation confirms that our results are not driven by low-frequency trends. Across all approaches, the coefficient on public debt remains negative, statistically significant, and similar in magnitude, reinforcing the conclusion that the relationship we document reflects genuine policy behavior rather than spurious comovements in trending variables.

[12] Intuitively, the SP-IV method can be viewed as a two-step procedure. In the first step, impulse responses at different horizons are estimated for each variable. In the second step, the Taylor rule is estimated using these responses in place of the original variables.

2.2 Ruling out alternative explanations

Taylor rules provide a parsimonious description of how monetary policy responds to macroeconomic conditions. In practice, however, the Federal Reserve bases its policy decisions on a broader information set than realized inflation and the output gap. It is therefore possible that the estimated relationship between the policy rate and the debt-to-GDP ratio reflects other factors correlated with debt that the Federal Reserve considers when setting interest rates. In this section, we empirically examine and rule out several such explanations.

The main idea is that if another variable influences interest-rate decisions through its effect on the public debt-to-GDP ratio, then controlling for that variable should eliminate the significance and explanatory power of debt. To test this hypothesis, we sequentially add potential control variables to the Taylor rule, as discussed below. We therefore estimate the following specification:

$$r_t = c + \alpha\pi_t + \beta y_t + \gamma d_t + \rho_1 r_{t-1} + \rho_2 r_{t-2} + \phi x_t + u_t, \tag{2}$$

where all variables are defined as before, and x_t denotes the additional control variables. In the following paragraphs, we examine different possible mechanisms.

2.2.1 Public debt as a predictor about future inflation or the output gap

It is established that the Federal Reserve conducts policy in a forward-looking manner responding not only to current inflation and output but also to their expected future values (Clarida, Gali, and Gertler, 2000). If this is the case, the public debt-to-GDP ratio could predict movements in future inflation or output, which would explain its significance in the estimated Taylor rule. To examine this possibility, we proceed in several ways.

First, we estimate equation (1) using the average of inflation and the output gap over the next four quarters as regressors.[13] Table A.12 reports the results, showing that the coefficient on the debt-to-GDP ratio remains negative and statistically significant. Its magnitude is also close to our benchmark specification, with an effect of about 50 basis points for a ten–percentage–point increase in public debt. We obtain the same conclusion when replacing realized values with Greenbook forecasts, averaged over the same four future quarters, as reported in Table A.13. In this case, the coefficient on debt is again negative and statistically significant, with a magnitude of about 0.7, similar to the estimate in Table 1. In both Tables A.12 and A.13, the coefficients on inflation and the output gap are positive and statistically significant.

[13]This approach—using realized future values averaged over several quarters—is common in empirical macroeconomics; see, for example, Barnichon and Mesters (2020).

Second, we estimate equation (2) by adding as controls the realized future values of inflation and the output gap over horizons of three, five, and ten years. Tables A.14, A.15, and A.16 report the results, showing the same pattern as before: the coefficient on the public debt-to-GDP ratio remains negative and statistically significant, while the coefficients on contemporaneous inflation and the output gap are both positive and statistically significant.

Taken together, these robustness exercises indicate that the negative relationship between the policy rate and the public debt-to-GDP ratio is not driven by information about future inflation or output. Public debt therefore appears to influence interest-rate decisions through a different channel.

2.2.2 Political pressure

Another possible explanation for our findings is that the Federal Reserve lowers the policy rate when the public debt-to-GDP ratio rises because of political pressure from the government. To examine this possibility, we add, as separate controls, the number of interactions—phone calls and in-person meetings—between the U.S. president and the Federal Reserve chair, taken from Drechsel (2024), and a measure of proximity to elections.[14] We therefore estimate equation (2) controlling for each of these two measures of political pressure in turn. Tables A.17 and A.18 show that the coefficient on the public debt-to-GDP ratio remains negative and statistically significant, with a magnitude similar to that in our benchmark specification, Table 1. The coefficients on inflation and the output gap also remain positive and significant. We interpret these findings as evidence that public debt influences monetary policy decisions beyond the direct effects of political pressure.

2.2.3 Economic conditions

A related concern is that the public debt-to-GDP ratio may reflect broader economic conditions. For example, during recessions, public debt typically rises as government spending increases, while the Federal Reserve lowers interest rates to stimulate the economy. It is therefore possible that the level of public debt simply reflects the state of the business cycle. To test this hypothesis, we estimate equation (2) including an indicator for NBER recession dates as an additional control. The results, reported in Table A.19, show that the coefficient on the debt-to-GDP ratio remains negative, statistically significant, and similar in magnitude to our benchmark specification in Table 1. Inflation and the output gap also remain positive and statistically significant. The recession indicator is negative and significant as well, consistent with the view that interest rates decline during downturns. However, the debt-

[14] This variable is defined as the number of quarters until the next midterm or presidential election.

to-GDP ratio continues to affect monetary policy beyond economic downturns, confirming that our results are robust to controlling for recessions.

Another potential explanation is that financial conditions are correlated with the demand for public debt, so that the debt-to-GDP ratio merely captures how easily households and firms can borrow. Indeed, Caballero, Caravello, and Simsek (2024) show that the Federal Reserve lowers interest rates when financial conditions deteriorate. To account for this possibility, we add as controls in equation (2) the BAA–AAA corporate bond spread, the Gilchrist and Zakrajšek (2012) excess bond premium, or the Chicago Fed National Financial Conditions Index (Tables A.20, A.21, and A.22). We also control for stock market conditions using either the CBOE Volatility Index (VIX) or S&P 500 returns (Tables A.23 and A.24). All these exercises show largely unaltered results, showing a negative and statistically significant coefficient on public debt-to-GDP, suggesting that public debt influences monetary policy independently of financial conditions or movements in equity markets.

2.3 Summary

Across all specifications and robustness exercises, we find a consistent result: when the public debt-to-GDP ratio rises, the Federal Reserve lowers the policy rate, conditional on inflation and the output gap. The effect is quantitatively stable and statistically significant across estimation methods, alternative measures of inflation, policy rates, and detrending approaches. It also remains robust when controlling for recessions, political pressure, financial and stock-market conditions. Taken together, the evidence indicates that public debt contains independent information relevant for monetary policy decisions.

This empirical regularity raises a natural question: through which mechanism does public debt influence interest-rate setting? The next section develops a theoretical framework to rationalize this finding.

3 A stylized New Keynesian model

This section presents a stylized New Keynesian model to explain our empirical finding that the Federal Reserve lowers the policy rate when the public debt-to-GDP ratio rises. The framework builds on the standard three-equation New Keynesian model, augmented with public bonds in households' utility, shocks to the utility value of holding bonds, and a fiscal rule in which taxes respond to debt, the interest rate, and output.

The key insight of the model is that shocks to households' demand for public debt generate negative comovements between the policy rate and public debt. These shocks lower the natural rate of interest, prompting a monetary authority that targets the natural rate to reduce the policy rate. Hence, the central bank does not respond to debt directly, but to the information that debt conveys about the natural rate.

3.1 Linearized model

In this section, we present the model's equilibrium conditions linearized around a steady state with zero inflation. A detailed derivation is provided in Appendix B.

$$y_t = \mathbb{E}_t y_{t+1} - (r_t - \mathbb{E}_t \pi_{t+1}) + \phi_B d_t - \eta_t \tag{E.E.}$$

$$\pi_t = \beta\, \mathbb{E}_t \pi_{t+1} + \kappa\, y_t, \tag{NKPC}$$

$$r_t = \phi_{R^*} R_t^* + \phi_\pi\, \pi_t + \phi_y\, y_t \tag{TR}$$

$$d_t = R\,(r_{t-1} + d_{t-1} - \pi_t) - \frac{tax}{d} tax_t \tag{gov't b.c.}$$

$$tax_t = \tau_y y_t + \tau_d d_{t-1} + \tau_R (r_t - \mathbb{E}_t \pi_{t+1}) + \tau_t \tag{tax rule}$$

Here, r_t denotes the nominal interest rate, y_t the output gap, π_t inflation, d_t the real value of public debt, tax_t lump-sum taxes in real terms, and R_t^* the natural rate of interest—that is, the equilibrium real rate in the flexible-price economy. The shocks η_t and τ_t follow AR(1) processes, and variables without time subscripts represent steady-state values.

Equation (E.E.) is the Euler equation, which features the novel term $\phi_B d_t$ arising from the assumption that government bonds enter households' utility. This assumption implies that output—and therefore consumption—depends directly on the level of public debt, breaking Ricardian equivalence. The parameter ϕ_B captures the strength of this channel: when $\phi_B = 0$, bonds provide no utility services, and the Euler equation reverts to its standard textbook form.

In equation (E.E.), the shock η_t represents changes in the utility value of holding government bonds. This shock captures exogenous shifts in households' preference for safe and liquid assets—public debt—when the perceived value of safety rises or precautionary motives strengthen. More broadly, η_t can be interpreted as a liquidity or safety shock that reflects increases in precautionary saving behavior during periods of greater uncertainty or perceived risk—such as when labor-income prospects weaken or financial conditions tighten. In this linearized framework, η_t is equivalent to a discount-factor shock, although the two differ in the quantitative model presented in Section 5.

Equation (NKPC) is the standard New Keynesian Phillips curve implied by price rigidities. Equation (TR) specifies the Taylor rule, which differs from the conventional formulation through the term $\phi_{R^*} R_t^*$: the monetary authority adjusts the nominal rate in response to movements in the natural rate. When the policy rate fully tracks the natural rate, inflation and the output gap remain unchanged in response to demand shocks, reproducing the divine coincidence of the standard New Keynesian framework. This assumption is central to our mechanism and provides a theoretical foundation for the empirical finding in Section 2: public debt is informative about the natural rate, but the central bank responds only to the natural rate itself.

Equation (gov't b.c.) is the linearized government budget constraint in real terms, and equation (tax rule) specifies the fiscal rule. The parameter τ_y captures the responsiveness of taxes to output fluctuations, τ_d governs how actively the government stabilizes debt, and τ_R measures the sensitivity of taxes to the real interest rate. The presence of τ_R is novel: it reflects that higher interest rates raise the cost of servicing public debt, inducing the fiscal authority to increase tax revenues. Finally, the shock τ_t represents an exogenous tax disturbance, capturing unexpected shifts in fiscal policy. A negative realization of τ_t can be interpreted as a fiscal stimulus or a transfer to households.

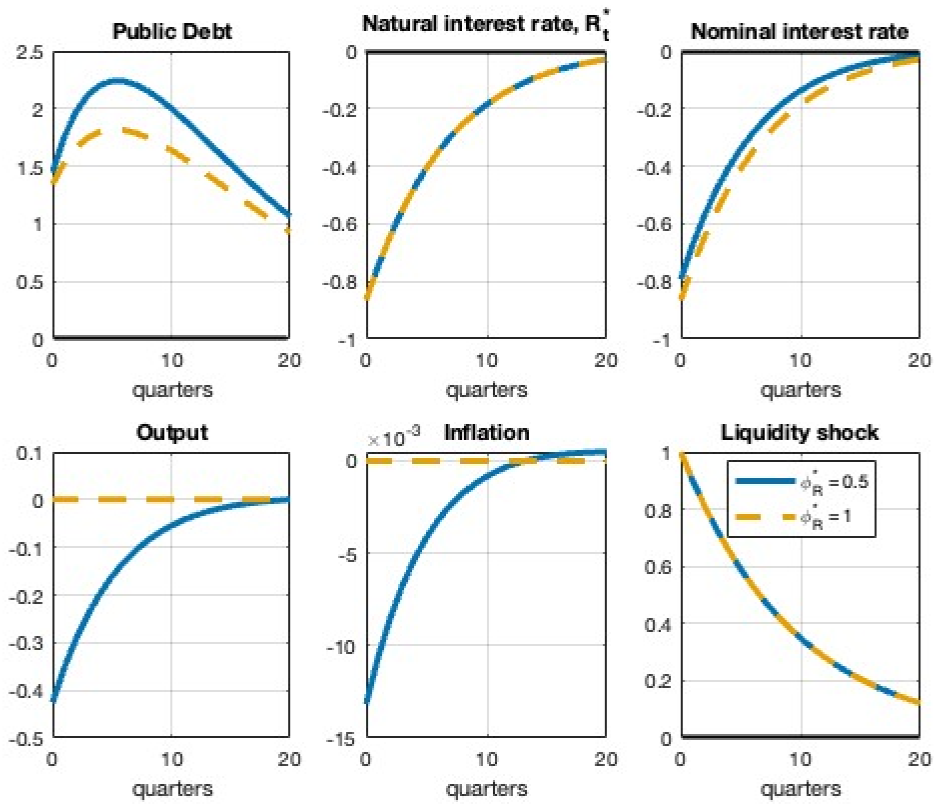
We next illustrate the dynamic implications of the model by examining, in turn, the responses of key variables to a liquidity shock and to a tax shock.

3.2 Impulse response functions

Figure 1 reports the impulse response functions (IRFs) to a liquidity shock. The panels in the figure display, respectively, the responses of public debt, the natural rate, the nominal interest rate, output, inflation, and the liquidity shock, under two alternative Taylor rules. In the first rule, the coefficient on the natural rate is set to $\phi_{R^*} = 0.5$ (blue line); in the second, to $\phi_{R^*} = 1$ (yellow line). When $\phi_{R^*} = 1$, the monetary authority fully stabilizes the economy: output and inflation remain at their steady-state levels, replicating the flexible-price allocation for these variables. This case corresponds to the familiar *divine coincidence* of the textbook New Keynesian model, in which monetary policy can simultaneously stabilize inflation and the output gap in response to demand shocks.

In Figure 1, debt and the nominal interest rate exhibit a negative comovement under both Taylor rules. Indeed, a positive liquidity shock increases households' demand for safe and liquid assets, leading them to reduce consumption and increase saving. In the case with $\phi_{R^*} = 0.5$ (blue line), this behavior lowers output and raises public debt, since the nominal interest rate does not decrease enough to offset the contraction in goods demand. When $\phi_{R^*} = 1$ (yellow line), monetary policy adjusts one-for-one with movements in the natural

Figure 1: Impulse response function to a liquidity shock

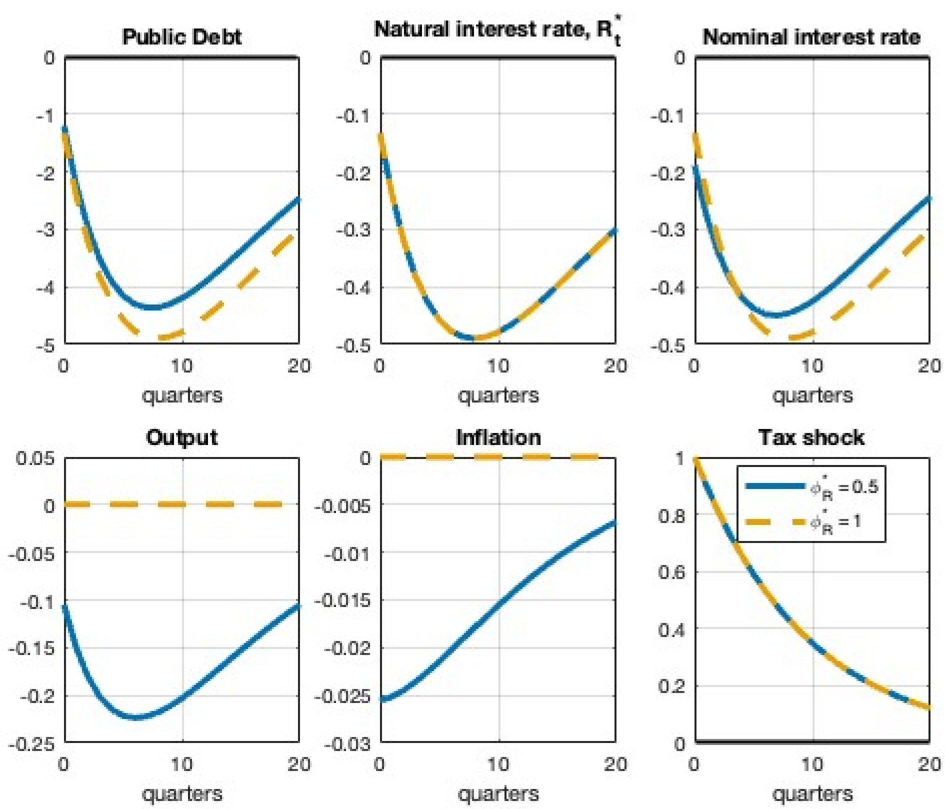


Notes: The figure shows the impulse response functions to a one-standard-deviation liquidity (safety) shock that raises households' preference for holding government bonds. The blue line corresponds to the Taylor rule with $\phi_{R^*} = 0.5$, while the yellow line corresponds to the rule with $\phi_{R^*} = 1$. The panels display, in order, the responses of public debt, the natural rate of interest, the nominal interest rate, output, inflation, and the liquidity shock itself. The figure highlights the negative comovement between public debt and the natural rate implied by the model's liquidity shock.

rate, preventing fluctuations in output and inflation. The reallocation of resources induced by the liquidity shock lowers the natural rate, R_t^*. As the central bank tracks movements in the natural rate, it reduces the nominal policy rate accordingly. Hence, even though the monetary authority does not respond to debt directly, debt remains highly informative about the natural rate. When public debt rises because of a stronger household demand for safe assets—a liquidity shock—the natural rate declines, and the central bank lowers the nominal interest rate.

The fiscal rule plays a key role in sustaining this mechanism. When taxes respond strongly to interest-rate movements—that is, when τ_R is large (close to one) in equation (11)—the fiscal authority accommodates changes in households' demand for debt, allowing debt issuance to adjust smoothly. When τ_R is small (for instance, $\tau_R = 0.2$), the government's debt supply becomes more inelastic, and the negative comovement between public debt and the natural rate disappears. In this case, the fiscal authority does not expand debt even when the cost of borrowing declines, lowering taxes. Figure B.1 confirms that, when $\tau_R = 0.2$, the correlation between debt and the natural rate becomes positive. In the quantitative model estimated in Section 5, we find that τ_R is indeed close to one and statistically significant, consistent with this interpretation. The corresponding estimates are reported in Table E.1.

Figure 2: Impulse response functions to a tax shock



Notes: The figure shows the impulse response functions to a one-standard-deviation tax shock that increases the primary surplus. The blue line corresponds to the Taylor rule with $\phi_{R^*} = 0.5$, while the yellow line corresponds to the rule with $\phi_{R^*} = 1$. The panels display, in order, the responses of public debt, the natural rate of interest, the nominal interest rate, output, inflation, and the tax shock itself. The figure highlights the positive comovement between public debt and the natural rate implied by the model's tax shock.

Our analysis suggests that demand-driven changes in public debt (liquidity shocks) generate a negative comovement between public debt and the nominal interest rate. The model also allows us to examine how this comovement changes when debt is driven by supply-side disturbances, such as a tax shock that increases fiscal revenues.

To illustrate this case, Figure 2 reports the impulse responses to a tax shock, constructed analogously to Figure 1, except that the last panel now displays the tax shock instead of the liquidity shock. The qualitative effects of a tax shock are independent of the monetary policy rule. When the fiscal authority raises taxes, public debt declines and households' wealth falls. Feeling poorer, households reduce consumption, generating a recession. To mitigate this downturn, the monetary authority lowers the policy rate. Tax shocks therefore induce a *positive* comovement between the nominal interest rate and public debt. The same mechanism operates in the flexible-price economy: higher taxes reduce wealth and consumption, lowering output and the natural rate of interest in tandem with the policy rate. Hence, under the assumption that the central bank tracks the natural rate, tax shocks naturally produce a positive association between public debt and the policy rate.

To sum up, the model can generate either positive or negative comovement between public debt and the natural rate, depending on the source of the disturbance. Liquidity (demand) shocks generate a negative correlation between public debt and the natural rate, whereas tax (supply) shocks produce a positive one. This distinction implies that our empirical finding of a negative coefficient on debt reflects the predominance of liquidity shocks over fiscal ones. Had tax shocks been the dominant driver of fluctuations, we would instead have found a positive relationship between debt and the policy rate. In Section 5, we extend the analysis to a quantitative DSGE framework to assess which type of shock dominates in explaining business-cycle dynamics.

4 The Natural Interest Rate

The model presented in Section 3 provides a mechanism consistent with our empirical finding that the Federal Reserve lowers the policy rate when public debt increases. The key idea is that the Federal Reserve does not target public debt directly but the natural rate of interest, and that public debt contains information about this measure. This implies that, once we control for the natural rate in equation (2), the coefficient on public debt should lose its significance.

To test this implication, we proceed as follows. In Section 4.1, we include existing estimates of the natural rate from the literature as an additional control in equation (2). The coefficient on the public debt-to-GDP ratio remains negative and statistically significant. This result reflects the fact that the existing measures of the natural rate do not incorporate information about public debt.

In Section 4.2, we therefore estimate a measure of the natural rate that explicitly incorporates information on public debt. When this debt-augmented natural rate is added to equation (2), the coefficient on the public debt-to-GDP ratio becomes insignificant, while the coefficient on the natural rate is positive and statistically significant.

4.1 Estimates in the literature of the natural rate

Guided by the model's intuition in Section 3, we estimate equation (2) controlling for the measure of the natural rate of interest constructed by Lubik and Matthes (2015). Table 2 reports the results. The table follows the same structure as Table 1: column (1) presents the OLS estimates, while the remaining columns report GMM estimates with different sets of instruments. In all specifications, the coefficient on the public debt-to-GDP ratio remains negative and statistically significant. Its magnitude, however, is roughly half of that reported in Table 1, consistent with the idea that debt is correlated with and informative about the natural rate. Since the Lubik and Matthes (2015) measure does not incorporate information on public debt, it cannot fully capture the underlying natural rate. While the coefficient on inflation is positive and statistically significant, as in Table 1, the coefficient on the output gap is negative and generally insignificant. This pattern reflects that the output gap and the natural rate measure convey similar information, making it difficult to disentangle their effects empirically.

Table 2: Taylor rule using the natural rate estimated by Lubik and Matthes (2015)

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.15***	1.19***	1.23***	1.20***	1.02***
	0.108	0.0825	0.055	0.078	0.064
y_t	-0.14	-0.07	-0.11*	-0.07	-0.20***
	0.118	0.079	0.063	0.075	0.047
d_t	-0.28**	-0.34***	-0.25***	-0.29***	-0.38***
	0.122	0.083	0.073	0.076	0.062
$R_t^{*,lm}$	4.41***	3.66***	4.12***	3.84***	4.31***
	0.631	0.399	0.367	0.355	0.332
ρ	0.47***	0.48***	0.37***	0.49***	0.45***
	0.132	0.0535	0.049	0.055	0.029
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the natural rate of interest estimated by Lubik and Matthes (2015), $R_t^{*,lm}$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

These results are not specific to the Lubik and Matthes (2015) measure. When we instead use alternative estimates of the natural rate from Laubach and Williams (2003) and Holston, Laubach, and Williams (2017), the coefficient on the public debt-to-GDP ratio remains negative and statistically significant. Table C.1 and Table C.2 report the corresponding results from estimating equation (2) with these measures.[15] In all these cases, the coefficients on inflation and the output gap are positive, while the coefficient on the natural rate is negative and often insignificant. This likely reflects the fact that the existing measures of the natural rate—including Lubik and Matthes (2015), Laubach and Williams (2003),

[15] Laubach and Williams (2003) provide two estimates of the natural rate using a one-sided and a two-sided filter. Table C.1 reports the results for the one-sided measure. The results are robust when the two-sided estimates are used.

and Holston, Laubach, and Williams (2017)—are constructed in a similar way, relying on information closely tied to the output gap. In particular, they typically assume that the natural rate depends primarily on trend productivity growth, which is highly correlated with the output gap. As a result, either the natural rate or the output gap tends to be significant, but not both.

However, other factors—such as the demand for public debt—also affect the natural rate, as in the model described in Section 3. For this reason, it is important to construct a measure of the natural rate that incorporates information on public debt. Instead, as already discussed, the measures of the natural rate analyzed thus far do not incorporate any information on public debt.

4.2 New measure of the natural rate incorporating public debt

In the existing literature, measures of the natural rate are typically constructed using information on output growth, inflation, and the real interest rate (Laubach and Williams, 2003; Lubik and Matthes, 2015; Holston, Laubach, and Williams, 2017). In what follows, we modify this estimation by incorporating the public debt-to-GDP ratio. To the extent that public debt is informative about the natural rate of interest, excluding it from the estimation yields an imperfect measure of the natural rate.

Following Lubik and Matthes (2015), we estimate the natural rate using a time-varying parameter vector autoregression (TVP–VAR). The model, originally developed by Primiceri (2005), can be written as

$$y_t = c_t + B_{1,t} y_{t-1} + \cdots + B_{k,t} y_{t-k} + u_t, \qquad t = 1, \ldots, T, \tag{3}$$

where y_t is an $n \times 1$ vector of observable variables, c_t is an $n \times 1$ vector of time-varying intercepts, and $B_{i,t}$ for $i = 1, \ldots, k$ are $n \times n$ matrices of time-varying coefficients. The vector of shocks u_t is heteroskedastic with variance–covariance matrix Ω_t satisfying $A_t \Omega_t A_t' = \Sigma_t \Sigma_t'$, where A_t is lower triangular and Σ_t is diagonal. All parameters of the model follow random-walk processes. Further details on the estimation and specification are provided in Appendix D.

We estimate the model including the variables in the following order:[16] public debt-to-GDP ratio, real GDP growth, CPI inflation, and the real interest rate. Lubik and Matthes

[16] The ordering of variables matters in any TVP–VAR because the matrix A_t is assumed to be triangular. The same issue arises in standard structural VARs identified through a Cholesky decomposition of the covariance matrix of the innovations. Reassuringly, however, as shown below, our results are robust to alternative orderings.

(2015) consider the same specification but exclude the public debt-to-GDP ratio and use PCE inflation. To maintain consistency with the empirical analysis in Section 2, we use CPI inflation instead of PCE inflation.[17] We adopt the same priors as Primiceri (2005), described in Appendix D, and include one lag of the observable variables.[18]

Once the model is estimated, we follow Lubik and Matthes (2015) and construct the natural rate of interest as the five-year-ahead forecast of the real interest rate, under the assumption that shocks continue to affect the economy but nominal frictions have disappeared.[19] Figure D.1 plots our estimate of the natural rate of interest (green line) alongside those of Lubik and Matthes (2015) and Holston, Laubach, and Williams (2017) (blue and red lines, respectively). The three series move closely together during the early part of the sample. However, after 2010, our estimate declines more sharply, reaching much lower and even negative levels during the 2010–2020 period. This pattern is consistent with the zero lower bound episode, when nominal rates were constrained and, as shown by Wu and Xia (2016), the shadow policy rate turned negative. Hence, it is plausible that the natural real interest rate was also negative during this period. Supporting this interpretation, recent estimates by Lubik and Matthes (2023) similarly report negative values for the natural rate in the 2010s.

The debt-augmented measure of the natural rate constructed above allows us to revisit the empirical relationship between public debt and the policy rate. Our hypothesis is that d_t appears as a relevant variable in the Taylor rule because it contains information about the natural rate of interest R_t^* beyond what is captured by inflation and the output gap. If this is the case, controlling for our new measure of the natural rate should fully absorb the effect of d_t on the policy rate.

To test this implication, Table 3 reports the estimates of equation (2) when our debt-informed natural rate is included as a control. The table is constructed as in Table 1: the first column presents OLS estimates, while the remaining columns report GMM estimates using different sets of instruments. The results show that the coefficient on the public debt-to-GDP ratio is no longer statistically significant, except in the last column. The coefficients on the natural rate and inflation are positive and statistically significant. Notably, the coefficient on the natural rate is close to one, implying that nominal interest rates move almost one-

[17] As discussed below, our results are robust to using PCE inflation instead of CPI inflation.

[18] Adding a fourth variable increases the number of estimated parameters substantially. For this reason, our baseline specification uses one lag, although results are similar when two lags are included.

[19] The real interest rate is obtained as the difference between the nominal interest rate and inflation expectations, where the latter are computed following the methodology of Laubach and Williams (2003). Specifically, they proxy inflation expectations with the forecast of the four-quarter-ahead percentage change in the core PCE price index—personal consumption expenditures excluding food and energy—generated from a univariate AR(3) estimated over the prior sample.

Table 3: Taylor rule estimates with our measure of the natural rate of interest

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	1.11***	1.09***	1.12***	1.05***	1.13***
	0.163	0.089	0.069	0.091	0.110
y_t	0.25	0.08	0.19***	0.19*	0.34***
	0.160	0.067	0.071	0.100	0.087
d_t	-0.24	0.01	-0.12	-0.10	-0.69***
	0.200	0.080	0.103	0.089	0.163
$R_t^{*,d}$	1.11***	1.56***	1.32***	1.37***	0.46**
	0.345	0.120	0.138	0.174	0.231
ρ	0.53***	0.29***	0.42***	0.45***	0.57***
	0.175	0.106	0.056	0.088	0.045
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and our estimate of natural rate of interest, $R_t^{*,d}$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

for-one with the natural rate. Finally, the coefficient on the output gap is positive but not always significant, consistent with the idea that it is difficult to disentangle the Federal Reserve's response to movements in the output gap and the natural rate, as the two contain correlated—though distinct—information.

These results provide supporting evidence that the Federal Reserve lowers the policy rate when public debt increases because debt conveys information about the natural rate, rather than because the central bank responds directly to debt. They also suggest that incorporating information on public debt is important when constructing measures of the natural rate of interest.

For this reason, and because the natural rate—rather than public debt itself—is the object of interest for the Federal Reserve, we estimate equation (1) using our measure of the natural rate in place of the public debt-to-GDP ratio. Table 4 reports the results and is constructed as Table 1. The estimated coefficients on inflation and the natural rate are both positive and statistically significant. The coefficient on the natural rate is close to 1.4, indicating that a one-percent increase in the natural rate is associated with roughly a 1.4-percent increase in the nominal interest rate. The coefficient on the output gap is again positive but not always significant. Overall, these findings provide additional evidence that the Federal Reserve targets a measure of the natural rate that embeds information about public debt.

Table 4: Taylor rule estimates with our measure of the natural rate of interest and without public debt

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	1.19***	1.13***	1.17***	1.10***	1.22***
	0.154	0.076	0.053	0.097	0.098
y_t	0.23	0.12	0.17**	0.22*	0.24***
	0.153	0.076	0.079	0.12	0.059
$R_t^{*,d}$	1.39***	1.51***	1.46***	1.46***	1.28***
	0.213	0.094	0.070	0.132	0.070
ρ	0.54***	0.29**	0.44***	0.47***	0.57***
	0.169	0.113	0.065	0.097	0.036
N	162	159	162	162	143

Notes: The table reports estimates of equation (1), where the debt-to-GDP ratio is replaced with our debt-informed measure of the natural rate of interest, $R_t^{*,d}$. The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and our estimate of the natural rate of interest, $R_t^{*,d}$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020), and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Taken together, the evidence in this section shows that the negative relationship between the policy rate and public debt reflects the information that debt conveys about the natural rate of interest. Once this debt-informed measure of the natural rate is included, public debt no longer explains monetary policy decisions. These findings support the view that the Federal Reserve adjusts its policy rate in response to changes in the public debt-to-GDP ratio, since public debt conveys information about the natural rate of interest beyond what is captured by output and inflation.

4.2.1 Robustness of the results

The results in Table 3 are robust to a wide range of empirical checks. First, we construct an alternative measure of the natural rate using PCE inflation in the TVP–VAR. We then re-estimate equation (2) using this alternative measure as a control and replace CPI inflation with PCE inflation for consistency. Table D.1 reports the results, showing once again that the coefficient on the debt-to-GDP ratio is no longer significant, while the coefficient on the natural rate remains positive and statistically significant, with a magnitude close to one.

Next, we estimate the TVP–VAR including the nominal interest rate directly and obtain the real rate as the difference between the forecasts of the nominal rate and inflation. Table D.2 presents the results, which confirm that the coefficient on the debt-to-GDP ratio remains insignificant, while the coefficient on the natural rate is positive and statistically significant. We also re-estimate our benchmark TVP–VAR with two lags; Table D.3 shows that the results are unchanged. Finally, the findings are robust to alternative priors for the means and variances of the random-walk processes governing the model's parameters.[20]

We perform the same set of robustness exercises for the regressions in Table 4. Table D.4, Table D.5, and Table D.6 report, respectively, the results obtained when using PCE inflation, the nominal rate, or two lags in estimating the TVP–VAR. Across all specifications, the coefficient on the debt-informed measure of the natural rate remains positive and statistically significant, with a magnitude relatively close to one.

Overall, these robustness exercises confirm that our main results are stable across alternative specifications, measures of inflation, and modeling choices.

5 DSGE model

So far, we have shown that the Federal Reserve lowers the policy rate when the public debt-to-GDP ratio increases. In Section 3, we proposed a mechanism that rationalizes this empirical fact: the Federal Reserve seeks to track the natural rate of interest, and public debt provides information about this unobservable variable. In Section 4, we presented supporting empirical evidence consistent with this interpretation.

Several open questions remain. Are shocks that generate a negative correlation between the natural rate and public debt quantitatively important for explaining business-cycle fluctuations? How do monetary and fiscal interactions influence these fluctuations and the transmission of shocks?

[20] For example, we experimented with different priors for the variance of innovations in residual volatility and in the evolution of the VAR coefficients. Results are available upon request.

To address these questions, we build and estimate a quantitative model based on Justiniano, Primiceri, and Tambalotti (2010). In line with the framework discussed in Section 3, we extend their DSGE model in three key dimensions. First, households derive utility from holding government bonds, and shocks to the utility value of bonds generate movements in the demand for public debt. Second, tax revenues respond to output, debt, and the interest rate, while government purchases are exogenous, as is standard in the DSGE literature. Third, monetary policy follows a Taylor rule augmented with the natural rate of interest, so that the nominal policy rate responds not only to inflation and the output gap but also to shifts in the natural rate.

5.1 Model environment

This subsection outlines the baseline model of the U.S. business cycle. The framework is a medium-scale DSGE model with a neoclassical growth core, augmented with several standard frictions. The economy is populated by six classes of agents: producers of the final good, intermediate-goods producers, households, employment agencies, a fiscal authority, and a monetary authority. The decision problems of the final-good producers, intermediate-goods producers, and employment agencies follow Justiniano, Primiceri, and Tambalotti (2010) and are described in detail in Appendix E.1. Below, we present the problems of the households, the fiscal authority, and the monetary authority.

Variables without a time script represents their steady-state levels.

5.1.1 Households problem

Each household j maximizes the expected lifetime utility

$$E_t \sum_{s=0}^{\infty} \beta^s b_{t+s} \left[\log(C_{t+s} - hC_{t+s-1}) - \varphi \frac{L_{t+s}(j)^{1+\nu}}{1+\nu} + \phi_B (B_{t+s} - \eta_t B)^2 \right], \tag{4}$$

where C_t denotes consumption, h is the degree of habit formation, $L_t(j)$ is hours worked by household j, and B_t is the holding of government bonds. The parameter $\phi_B > 0$ governs the strength of households' preference for holding government bonds. Consumption and bond holdings are not indexed by j because the presence of complete state-contingent securities ensures that, in equilibrium, all households choose identical consumption and asset positions.

The novelty in equation (4) relative to the standard literature is the inclusion of the term $\phi_B(B_t - \eta_t B)^2$, which captures the idea that households value government bonds not only for their pecuniary returns but also for the services they provide. This assumption has two key implications. First, it breaks Ricardian equivalence, since public debt directly affects households' decisions. Second, it establishes a direct link between the level of public debt and interest rates. This feature motivates our use of the level of public debt in the empirical analyses presented in Section 2 and Section 4.

Beyond these theoretical implications, the term also has a clear economic interpretation. As emphasized by Krishnamurthy and Vissing-Jorgensen (2012), government debt is both safe and liquid. The additional utility term can therefore be viewed as capturing the liquidity and safety services that government bonds provide beyond their financial return. We thus refer to η_t as a *liquidity* or *safety* shock. This shock evolves according to

$$\log(\eta_t) = (1-\rho_\eta) log(\eta) + \rho_\eta \log(\eta_{t-1}) + \varepsilon_{\eta,t}, \qquad \varepsilon_{\eta,t} \overset{i.i.d.}{\sim} \mathcal{N}(0, \sigma_\eta^2),$$

and represents exogenous shifts in households' demand for safe and liquid assets. An increase in η_t raises the utility derived from holding government bonds, inducing households to save more and consume less, thereby generating a recessionary effect.

This shock admits several interpretations. It microfounds the *risk-premium* shock of Smets and Wouters (2007) when public debt supply is zero (Fisher, 2015); it corresponds to the *spread* or *flight-to-safety* shocks commonly studied in the international literature (Eichenbaum, Johannsen, and Rebelo, 2021; Kekre and Lenel, 2024); and it can be viewed as capturing increases in idiosyncratic risk (Aiyagari, 1994; Bayer et al., 2019) or in the riskiness of capital returns (Li and Merkel, 2025). More broadly, it can also be interpreted as a tightening of borrowing constraints, which limits households' ability to save in safe assets—here, government debt.

In addition to the liquidity shock, households are also subject to a standard intertemporal preference shock. In equation (4), b_t represents a shock to the discount factor, which affects both the marginal utility of consumption and the marginal disutility of labor. This shock follows the stochastic process

$$\log b_t = \rho_b \log b_{t-1} + \varepsilon_{b,t}, \qquad \varepsilon_{b,t} \overset{i.i.d.}{\sim} \mathcal{N}(0, \sigma_b^2),$$

and captures temporary changes in households' willingness to substitute consumption intertemporally.

Having described households' preferences and the relevant shocks, we now turn to their budget constraint. In nominal terms, the household's flow budget constraint is

$$P_t C_t + P_t T_t + P_t I_t + B_t \leq R_{t-1} B_{t-1} + Q_t(j) + \Pi_t + W_t(j) L_t(j) + r_t^k u_t \bar{K}_{t-1} - P_t a(u_t) \bar{K}_{t-1},$$

where I_t is investment, T_t is lump-sum taxes, R_t is the gross nominal interest rate, $Q_t(j)$

denotes the net cash flow from household j's portfolio of state-contingent securities, and Π_t is the per-capita profit accruing to households from firm ownership.

Households own the capital stock and choose the utilization rate u_t, which transforms physical capital into effective capital according to

$$K_t = u_t \bar{K}_{t-1}.$$

Effective capital is rented to firms at the rate r_t^k, while the cost of utilization is given by $a(u_t)$ per unit of physical capital. In the steady state, $u = 1$, $a(1) = 0$, and $\chi \equiv a''(1)/a'(1)$ measures the curvature of the utilization cost function. Under log-linearization, χ is the only parameter of $a(u_t)$ that affects the model's dynamics.

The accumulation of physical capital follows

$$\bar{K}_t = (1-\delta)\bar{K}_{t-1} + \mu_t \left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right] I_t,$$

where δ is the depreciation rate and $S(\cdot)$ denotes the investment adjustment-cost function. The investment-specific shock μ_t captures exogenous variation in the efficiency with which final goods are transformed into productive capital. This shock evolves according to

$$\log \mu_t = \rho_\mu \log \mu_{t-1} + \varepsilon_{\mu,t}, \qquad \varepsilon_{\mu,t} \overset{i.i.d.}{\sim} \mathcal{N}(0, \sigma_\mu^2),$$

where ρ_μ measures the persistence of the shock.

As in Erceg, Henderson, and Levin (2000), each period a fraction ξ_w of households cannot freely adjust their wage and instead follows the indexation rule

$$W_t(j) = W_{t-1}(j), (\pi_{t-1} e^{z_{t-1}})^{\iota_w} (\pi e^\gamma)^{1-\iota_w},$$

where z_t denotes the growth rate of the exogenous technology process, $\Delta \log A_t$:

$$\Delta \log A_t \equiv z_t = (1-\rho_z)\gamma + \rho_z z_{t-1} + \varepsilon_{z,t}.$$

The remaining fraction $(1-\xi_w)$ of households reoptimizes its wage $W_t(j)$ by maximizing utility subject to the budget constraint and the demand for differentiated labor $L_t(j)$, which is aggregated into total labor by *employment agencies* as described in Appendix E.1.3.

5.1.2 Fiscal and monetary authority

The fiscal authority's budget constraint in real terms is

$$D_t + T_t = R_{t-1}\pi_t^{-1}D_{t-1} + G_t,$$

where D_t denotes the stock of real public debt, T_t represents lump-sum taxes, and G_t is government spending. Government purchases are assumed to be an exogenous, time-varying fraction of output, as in Justiniano, Primiceri, and Tambalotti (2010):

$$G_t = \left(1 - \frac{1}{g_t}\right) Y_t,$$

where g_t follows the stochastic process

$$\log g_t = (1-\rho_g)\log g + \rho_g \log g_{t-1} + \varepsilon_{g,t}, \qquad \varepsilon_{g,t} \overset{i.i.d.}{\sim} \mathcal{N}(0,\sigma_g^2). \tag{5}$$

This specification implies that higher values of g_t correspond to periods of higher government expenditure relative to output.

Given the assumption of bonds in the utility function, Ricardian equivalence does not hold, since the path of public debt directly affects households' choices. Therefore, the specification of the fiscal rule governing taxes, T_t, is crucial for the model's dynamics. We assume that the fiscal authority follows the tax rule, expressed in real terms,

$$T_t - \tilde{T} = \tau_y Y_t + \tau_{yy} Y_{t-1} + \tau_d D_{t-1} + \tau_R \pi_{t+1}^{-1} R_t G_t + \rho_T T_{t-1} + \tau_t,$$

where $\tilde{T}$ denotes the steady-state level of tax revenues. The coefficients τ_y and τ_{yy} capture the procyclicality of fiscal policy, implying that tax revenues increase when output expands, while τ_d measures the responsiveness of taxes to the outstanding stock of public debt, governing the speed of debt stabilization. Both terms are standard in the fiscal-policy literature. The parameter τ_R governs the sensitivity of taxes to interest-rate fluctuations and, therefore, to the cost of debt servicing. A positive value of τ_R implies that when interest rates rise and debt servicing becomes more expensive, the fiscal authority raises tax revenues to maintain fiscal discipline. When $\tau_R = 0$, as typically assumed in the literature, fiscal policy is completely inelastic to interest-rate changes. The term ρ_T allows for partial adjustment or smoothing of tax revenues over time. Finally, τ_t represents an exogenous fiscal disturbance, which evolves according to

$$\log \tau_t = \rho_\tau \log \tau_{t-1} + \varepsilon_{\tau,t}, \qquad \varepsilon_{\tau,t} \overset{i.i.d.}{\sim} \mathcal{N}(0,\sigma_\tau^2).$$

This shock can be interpreted as a lump-sum fiscal stimulus or consolidation measure that temporarily alters government revenues.

Fiscal and monetary policy jointly determine the dynamics of public debt and interest rates. While the fiscal rule governs how the government adjusts taxes to stabilize debt, monetary policy sets the short-term nominal rate according to the following Taylor rule:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\mathbb{E}R^*_{t+20}}{R^*}\right)^{\phi_{R^*}} \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{X_t}{X^*_t}\right)^{\phi_x}\right]^{1-\rho_R} \left[\frac{X_t/X_{t-1}}{X^*_t/X^*_{t-1}}\right]^{\phi_{\Delta x}} \eta_{mp,t} \qquad (6)$$

where R denotes the steady-state gross nominal interest rate and R^* the steady-state natural rate. Output is defined as $X_t = C_t + I_t + G_t$, and variables with an asterisk refer to the natural (flexible-price) economy without markup shocks. Hence, $\frac{X_t}{X^*_t}$ and $\frac{X_t/X_{t-1}}{X^*_t/X^*_{t-1}}$ represent, respectively, the output gap and its growth rate. The monetary policy shock $\eta_{mp,t}$ follows the process

$$\log \eta_{mp,t} = \rho_{mp} \log \eta_{mp,t-1} + \varepsilon_{mp,t}, \qquad \varepsilon_{mp,t} \overset{i.i.d.}{\sim} \mathcal{N}(0, \sigma^2_{mp}).$$

The novelty in equation (6) relative to Justiniano, Primiceri, and Tambalotti (2010) and the broader DSGE literature is the inclusion of the term $\left(\frac{\mathbb{E}_t R^*_{t+20}}{R^*}\right)^{\phi_{R^*}}$, which captures the monetary authority's response to variations in the natural rate. This feature is central to our mechanism: as shown empirically in Section 2, public debt is informative about and negatively correlated with the natural rate, R^*_t. For consistency with our empirical measure—constructed as a five-year-ahead forecast in Section 4.2—we assume that the monetary authority responds to a forecast of the natural rate rather than its contemporaneous value. This assumption also reflects a realistic feature of policy behavior:[21] the natural rate is difficult to estimate in real time, and high-frequency fluctuations in its measured value may reflect noise rather than persistent movements. By responding to $\mathbb{E}_t R^*_{t+20}$, the central bank smooths its reaction to short-term volatility while adjusting policy rates in line with more persistent shifts in the natural rate.

[21] As pointed out by Vice Chairman of the Federal Reserve Roger W. Ferguson Jr in 2004 (Ferguson, 2004): "One way of providing that benchmark is to consider what level of the real federal funds rate, if allowed to prevail for several years, would place economic activity at its potential and keep inflation low and stable. [...] This definition makes clear that the most relevant aid in policymaking is an *intermediate-run measure*, in that there may be forces at work in the shorter run that push spending away from potential output even if the real rate were pegged at this benchmark rate." Our assumption is that the intermediate-run horizon corresponds to five years.

5.1.3 Market clearing

The aggregate resource constraint must hold in every period:

$$C_t + I_t + G_t + a(u_t), \overline{K}_{t-1} = Y_t,$$

which follows from combining the budget constraints of households and the fiscal authority with the zero-profit conditions of final-good producers and employment agencies. In addition, the market for government bonds clears each period, so that households' demand for bonds equals the public debt issued by the government:

$$B_t = D_t.$$

5.1.4 Solution

Because the technology process A_t follows a unit-root process, consumption, investment, capital, real wages, output, and public debt fluctuate around a stochastic balanced-growth path. To solve the model, we proceed in three steps. First, we rewrite all equations in terms of detrended variables. Second, we compute the non-stochastic steady state of the transformed system and log-linearize it around that steady state. Third, we solve the resulting linear rational-expectations system to obtain its state-space representation, which forms the basis for the Bayesian estimation of the model.

5.2 Solution and Bayesian inference

As is standard in the DSGE literature, we estimate the model using Bayesian methods to characterize the posterior distribution of the structural parameters. The posterior combines the likelihood function—derived from the state-space representation—with prior distributions for the parameters. The observable variables used to compute the likelihood are the logarithmic differences of GDP, consumption, investment, and real wages, together with inflation, the federal funds rate, hours worked, and the logarithmic of the ratio of public debt to GDP.

The model does not capture differential long-run trends between GDP and public debt. Following Bilbiie, Primiceri, and Tambalotti (2023), we therefore detrend the logarithmic of the ratio of public debt to GDP using a band-pass filter that extracts fluctuations with periodicities shorter than 15 years. Because this variable is filtered, we include measurement error in its observable equation, while all other observables are assumed to be measured without error.

The data are quarterly and span the period from 1979:Q3 to 2019:Q4, consistent with the empirical analyses in Section 2 and Section 4. Appendix E.2 provides details on the data and describes how the observed variables are mapped into their model counterparts. Two parameters are fixed. Following the literature, we set the quarterly depreciation rate of capital, δ, to 0.025 and the steady-state ratio of government spending to GDP, $(1 - 1/g)$, to 0.22, as in Justiniano, Primiceri, and Tambalotti (2010).

The prior and posterior estimates of the structural parameters are reported in Table E.1 in Appendix E.3. Most priors are consistent with those commonly used in the literature. For parameters appearing in Justiniano, Primiceri, and Tambalotti (2010), we adopt almost identical priors. For the fiscal block, we use values close to those in Leeper, Traum, and Walker (2017) whenever available, and otherwise assign diffuse priors. Finally, we set a prior for the bond-preference parameter, ϕ_B, to ensure that debt has non-trivial effects on households' choices. This prior is relatively tight, since unconstrained estimation tends to push ϕ_B toward very small values, in which case tax shocks would have negligible real effects and would instead behave like measurement errors—accounting for fluctuations in debt without affecting equilibrium dynamics. This outcome arises because we normalize the liquidity (or safety) shock in the bond Euler equation to enter with a unit coefficient, so that ϕ_B does not scale the propagation of this shock.

Furthermore, the intertemporal preference, price-markup, and wage-markup shocks are also normalized to enter with unit coefficients in the consumption Euler equation, the price-inflation equation, and the wage-setting equation, respectively.

5.3 Model Results

The estimated model allows us to address several key questions through a series of quantitative exercises. First, in Section 5.3.1, we show that liquidity shocks account for roughly 40% of business-cycle fluctuations in GDP, public debt, the nominal interest rate, and the natural rate. Second, in Section 5.3.2, we analyze the dynamic effects of a liquidity (or safety) shock on the economy. Third, in Section 5.3.4, we use simulated data from the model to demonstrate that our mechanism can quantitatively rationalize the empirical relationship estimated in Section 2. Finally, in Section 5.3.3, we conduct counterfactual simulations to assess how the economy would behave under alternative monetary or fiscal rules.

5.3.1 Variance decomposition

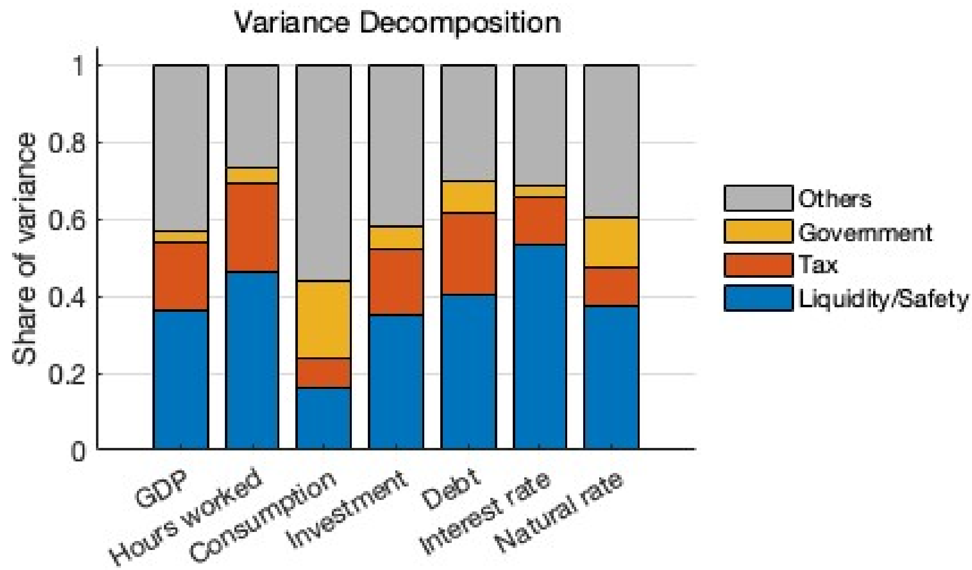
A central contribution of the paper is to show that public debt contains information about the natural rate and that the Federal Reserve responds to this information rather than to debt itself. The mechanism described in Section 3 relies on liquidity (or safety) shocks, which generate a negative comovement between debt and the natural rate. When such shocks occur, an increase in debt signals a decline in the natural rate, prompting the monetary authority to lower the nominal interest rate. For this mechanism to be quantitatively relevant, liquidity shocks must account for a sizable share of the fluctuations in the nominal rate, the natural rate, and public debt.

For this reason, we compute the variance decomposition of the main macroeconomic variables implied by the estimated model, including the natural rate. Figure 3 reports the contribution of the liquidity, tax and government purchase shocks to the variance of the *levels* of GDP, hours worked, consumption, investment, the public-debt-to-GDP ratio, the nominal interest rate, and the natural rate. The variance decomposition is based on the spectral representation of the model and focuses on cyclical components with periodicities between 6 and 32 quarters, following Stock and Watson (1999). For the first six variables—those that are observable in the data—the decomposition is computed directly from the observables. By contrast, the natural rate is unobserved, and its variance decomposition is imputed from the model's solution. To obtain the decomposition, we use the spectrum of the estimated DSGE model combined with an inverse first-difference filter for output, hours worked, consumption, and investment.

Figure 3 shows that liquidity shocks (in blue) account for roughly 40% of the variation in GDP, hours worked, investment, public debt, the nominal interest rate, and the natural rate, and about 20% of the variation in consumption. These shocks therefore play a central role in explaining business-cycle fluctuations. This result is consistent with the interpretation of liquidity shocks as the Smets and Wouters (2007) "risk-premium" shock, which also explains a large share of cyclical variation in standard DSGE models. The main novelty of our framework is that these shocks jointly drive movements in the debt-to-GDP ratio and the natural rate, creating a systematic link between the two variables. This connection allows the Federal Reserve to exploit information contained in public debt when setting the policy rate.

Figure 3 also shows that tax shocks (in red) account for part of the variation in GDP, hours worked, investment, and public debt. However, compared with liquidity shocks, they explain a smaller share of the fluctuations in the natural rate and the nominal interest rate. In canonical DSGE models such as Christiano, Eichenbaum, and Evans (2005); Smets and Wouters (2007); Justiniano, Primiceri, and Tambalotti (2010), these shocks have no effect on business-cycle dynamics because Ricardian equivalence holds. In contrast, in our framework—where Ricardian equivalence is broken—tax shocks contribute meaningfully to macroeconomic fluctuations. Government purchase shocks (in yellow) explain a smaller

Figure 3: Posterior variance decomposition at the business cycle frequency



Notes: Business-cycle frequencies correspond to cyclical components with periods between 6 and 32 quarters. The variance decomposition is obtained from the spectral representation of the DSGE model. An inverse first-difference filter is applied to GDP, consumption, and investment to recover their level components. The spectral density is computed from the model's state-space representation using 500 frequency bins covering the range of business-cycle periodicities. The figure shows that liquidity (safety) shocks account for an important share of business-cycle fluctuations.

fraction of the variance than typically found in the DSGE literature, largely because our model also allows for tax shocks. Nevertheless, these shocks still account for a nontrivial share of the variation in consumption, around 20%.

Finally, Table E.2 reports the variance decomposition for all observable variables and for the natural rate. Technology shocks account for roughly 25% of the variation in GDP and consumption, while investment-specific shocks explain about 20% of the variability in investment. Price and wage markup shocks together explain around 70% of the variation in price and wage inflation—a larger share than typically found in the literature. However, this result is consistent with recent evidence, such as Stock and Watson (2020) and Hazell et al. (2022), documenting a flattening of the Phillips curve beginning in the 1980s, which coincides with the start of our sample period. Our estimation sample also differs from much of the DSGE literature, as it begins later and extends through 2019, potentially amplifying the relative importance of markup shocks in explaining inflation dynamics.

5.3.2 Impulse response function to a liquidity shock

In Section 3, we showed that a positive liquidity (or safety) shock leads to an increase in public debt and a decline in both the nominal and natural interest rates. This result provided the intuition behind our main empirical finding in Section 2: the Federal Reserve does not react to public debt per se, but to the information debt conveys about the natural rate. We now ask whether this mechanism remains valid in a richer and empirically grounded environment—specifically, in the estimated DSGE model that captures the main features of the U.S. economy.

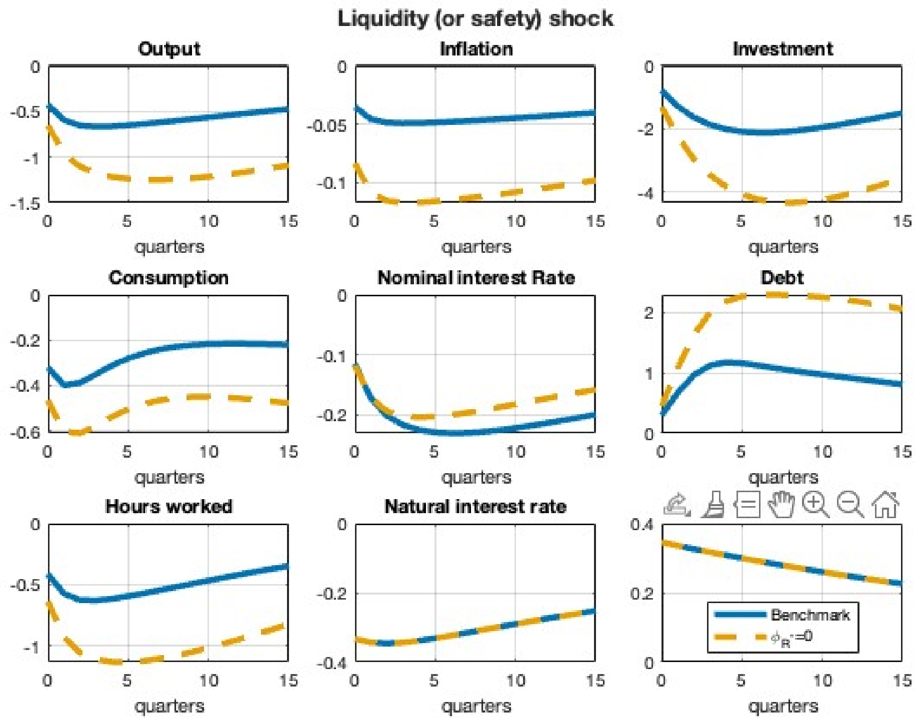
For this reason, Figure 4 reports the impulse response functions (IRFs) to a liquidity shock under two alternative Taylor rules: the estimated rule (in blue) and a counterfactual rule in which the coefficient on the natural rate is set to zero (in yellow). The panels display, in order, the responses of output, inflation, investment, consumption, the nominal interest rate, public debt, hours worked, the natural rate, and the liquidity shock.

Figure 4 corroborates the intuition developed in Section 3. When a positive liquidity shock hits the economy, the nominal interest rate falls and public debt rises. Households shift resources from consumption toward the safe asset—public debt—leading to a decline in output, investment, and hours worked. To counteract this recessionary effect, the monetary authority lowers the policy rate, regardless of whether it explicitly targets the natural rate. However, when the policy rule includes the natural rate, the nominal rate declines more sharply, providing a stronger stabilization of the economy. In this case, the contractions in output, inflation, investment, consumption, and hours worked, as well as the increase in public debt, are all more moderate. Thus, it is optimal for the monetary authority to target the natural rate in response to liquidity shocks. The same insight derived from the simple model in Section 3 therefore holds in the full quantitative model, reinforcing the interpretation of our empirical findings in Section 2.

The mechanism that links public debt to the natural rate also helps to illustrate how our model departs from standard DSGE frameworks. As already discussed, the liquidity shocks in our model microfound the Smets and Wouters (2007) "risk-premium" shock when public debt is held fixed. In that case, the mechanism linking debt and the natural rate disappears: if public debt cannot adjust, the negative correlation between the two variables vanishes, and debt no longer contains information about the natural rate. This comparison highlights that allowing debt to move endogenously is essential for our mechanism to operate.

Beyond validating the mechanism discussed above, the impulse responses also reproduce the typical dynamics of a recession. A positive liquidity shock generates a contraction in output, investment, and consumption, together with deflation and a decline in the nominal

Figure 4: Impulse response functions to a liquidity (or safety) shock



Notes: The figure shows the impulse response functions to a one-standard-deviation liquidity (safety) shock in the estimated DSGE model. The blue line corresponds to the estimated Taylor rule, while the yellow line corresponds to the rule with no response to the natural rate, $\phi_{R^*} = 0$. The panels display, in order, output, inflation, investment, consumption, the nominal interest rate, public debt, hours worked, marginal cost, and the natural rate of interest. The figure highlights the negative comovement between public debt and the natural rate implied by the model's liquidity shock.

interest rate, while public debt rises. These patterns explain why liquidity shocks account for a large share of business-cycle fluctuations, as shown in Section 5.3.1.

In contrast to liquidity shocks, tax shocks—reported in Figure E.1—produce similar recessionary dynamics but with opposite implications for public debt. A tax increase leads to a contraction in output, investment, and consumption, accompanied by deflation and a decline in both the natural and nominal interest rates. However, public debt falls, thereby generating a positive comovement between the natural rate and debt. When the monetary authority targets the natural rate, the declines in output, consumption, investment, and inflation are more moderate. At the same time, the reduction in public debt is more pronounced, whereas for a liquidity shock, targeting the natural rate leads to a smaller increase in debt. This asymmetry arises because debt moves together with output: lower output reduces tax revenues, leading to a smaller fiscal surplus and, consequently, a sharper fall in debt. These differences explain the distinct patterns of debt dynamics under the two Taylor rules across the two types of shocks.

5.3.3 Estimate of the Taylor rule with simulated data

We interpret the empirical result in Section 2—that the Federal Reserve lowers the nominal interest rate when the public debt-to-GDP ratio increases—not as evidence that the Federal Reserve reacts to debt itself, but as reflecting that debt provides information about movements in the natural rate, to which policy responds. In this section, we use the estimated DSGE model to verify whether this mechanism can quantitatively reproduce the same relationship observed in the data.

To this end, we test whether the model can replicate the empirical finding that the policy rate falls when public debt rises, even though the central bank does not react to debt directly. To do so, we simulate 2,000 artificial economies using parameters fixed at the posterior mode, each for 250 periods, discarding the first 100 observations. In these simulations, the monetary authority sets the nominal interest rate in response to the natural rate but not to public debt. We then estimate, by ordinary least squares, equation (6), but replacing the natural rate with the debt-to-GDP ratio. If our mechanism is correct—namely, that public debt is informative about the natural rate—the regression on simulated data should yield a negative and statistically significant coefficient on debt.

Table 5 reports the results of this simulation exercise under several scenarios. The first column lists the true parameters used in the model. The second column presents the regression results when all shocks are included. The third column removes monetary policy shocks to address the endogeneity between the interest rate and public debt. The fourth column reports results when the economy is simulated only under liquidity shocks, and the last column when it is simulated only under fiscal shocks—that is, government spending and tax shocks.

The table reveals a clear pattern: whenever liquidity shocks are present (columns 2, 3, and 4), the coefficient on public debt is negative. In column 2, where all shocks are included, the coefficient is not statistically significant. However, this specification suffer of the endogeneity problem introduced by monetary policy shocks. Once these shocks are excluded (column 3), the estimated coefficient becomes negative and significant. When only liquidity shocks are included (column 4), the coefficient remains negative, larger in magnitude, and statistically significant. Its value, around -0.3, is less than half of the empirical estimate of -0.7 reported in Table 1. Although the simulated coefficient is smaller, the fact that the model reproduces the correct sign supports our interpretation of the empirical finding. Indeed, we are estimating a misspecified regression that omits the natural rate, so a negative coefficient is not mechanically guaranteed.

Table 5: Estimated Taylor rule using simulated data

	Model	All shocks	No monetary shock	Only liquidity shock	Only fiscal shocks
R_{t-1}	0.771	0.832	0.857	0.710	0.641
		(0.039)	(0.018)	(0.005)	(0.019)
y_t	0.012	0.128	0.116	-0.026	0.108
		(0.068)	(0.032)	(0.012)	(0.004)
π_t	1.484	2.388	2.610	4.188	1.524
		(0.614)	(0.365)	(0.105)	(0.073)
d_t	–	-0.167	-0.269	-0.331	0.130
		(0.245)	(0.096)	(0.019)	(0.015)
Δy_t	0.140	0.107	0.193	0.163	0.133
		(0.028)	(0.008)	(0.001)	(0.004)

Notes: The table reports ordinary least squares estimates of equation (6) with the natural-rate term replaced by the debt-to-GDP ratio using simulated data with parameters fixed at the posterior mode. We simulate 2,000 economies for 250 periods and discard the first 100 observations; in the simulations, policy reacts to the natural rate but not to debt. The first column shows the true parameter values implied by the model. The second column reports estimates when all structural shocks are included. The third column excludes monetary policy shocks. The fourth and fifth columns display results when the economy is simulated only under liquidity shocks and only under fiscal shocks (government spending and tax shocks), respectively. Standard errors are reported in parentheses.

On the other hand, when only fiscal shocks are included—that is, tax and government spending shocks (column 5)—the coefficient on public debt becomes positive. This result further supports the view that the negative relationship found in the data reflects the predominance of liquidity shocks during the analyzed period, which were the main drivers of U.S. business-cycle fluctuations, as documented in Section 5.3.1.

Finally, across all specifications, the estimated coefficients on the lagged interest rate and on the growth rate of the output gap are close to the true values reported in the first column. In contrast, the coefficient on the output gap itself deviates substantially from the model-implied value. This likely reflects the close relationship between the natural rate and the output gap in the model, and the exclusion of the natural rate from the regression. As a result, the true coefficient on the output gap is difficult to recover, which helps explain why this term is often insignificant in Section 4.

Together, these simulation results confirm that the estimated model can quantitatively reproduce the key empirical relationship between public debt and monetary policy documented in the data.

5.3.4 Monetary and fiscal rules

So far, we have taken a specific stand on the conduct of monetary and fiscal policy by specifying a Taylor rule and a fiscal rule. In particular, we have assumed that the monetary authority targets the natural rate, an assumption that is crucial to rationalize the negative coefficient estimated in equation (1): because public debt is informative about the natural rate, policy must respond to it. While there is evidence that the Federal Reserve does target the natural rate (e.g., Cúrdia et al. (2015)), many DSGE models abstract from this feature. In what follows, we use the estimated model to study how alternative policy specifications—on both the monetary and the fiscal side—affect the volatility of key macroeconomic variables, namely output, inflation, the nominal interest rate, and public debt.

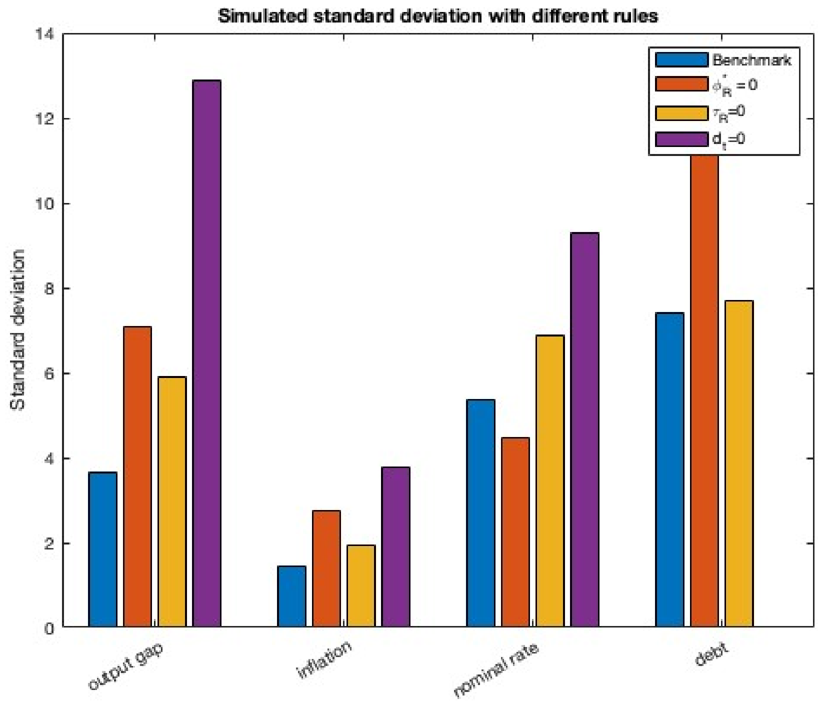
For this reason, we simulate the economy as done in Section 5.3.3, and compute the unconditional long-run standard deviation of output inflation nominal rate and debt under a Taylor rule that target or not the natural rate. Furthermore, given our structural model, we can also analyze what would happen under different fiscal rules. We study two different fiscal rules, one in which the fiscal authority is not reacting to variations in the interest rate, i.e. $\tau_R = 0$, one in which the fiscal authority targets a fix level of public debt. This second fiscal rule allows us to interpret our economy as the Smets and Wouters (2007) model, this motivates our choice.

Figure 5 reports the results of the standard deviation of output gap, inflation, the nominal rate, and debt under the four different discussed rules. In blue, the estimated model, our benchmark specification, in red the model in which the monetary authority does not target the natural rate, in yellow the fiscal rule does not react to variations in the interest rate, and in purple a fiscal rule such that debt is keep fix to a constant level.

Comparing the Taylor rule that targets the natural rate (in blue) with the one that does not (in red), Figure 5 shows that fluctuations in inflation and the output gap—key objectives of monetary policy—are much larger when the natural rate is not targeted. Public debt also exhibits greater volatility in this case. By contrast, not targeting the natural rate slightly reduces fluctuations in the nominal interest rate. This is suggestive that it is optimal for a monetary authority that wants to close the output gap and reduce inflation, as stated in the Federal Reserve dual mandate, to target the natural rate.

Next, we compare our benchmark model with a version in which the fiscal authority does not adjust taxation in response to interest-rate movements, that is, $\tau_R = 0$ (yellow bars in Figure 5). Under this alternative fiscal rule, the standard deviations of the output gap, inflation, and the nominal interest rate are larger, while the volatility of public debt remains roughly unchanged. This happens because, following a positive liquidity shock—the main

Figure 5: Standard deviation under different rules



Notes: The figure reports the long-run standard deviation of the output gap, inflation, the nominal interest rate, and public debt under four alternative policy rules. The blue bar corresponds to the estimated benchmark rule. The red bar refers to the case in which the monetary authority does not respond to the natural rate, $\phi_{R^*} = 0$. The yellow bar corresponds to the case in which the fiscal authority does not react to changes in the interest rate, $\tau_R = 0$. The purple bar refers to the case in which the fiscal authority targets a fixed level of public debt, $d_t = 0$.

driver of business-cycle fluctuations—households increase their demand for safe assets and reduce consumption. Since the fiscal authority does not lower taxes to accommodate this higher demand for government bonds, the supply of debt does not expand, amplifying the contraction in consumption and output. To counteract the deeper recession, the monetary authority lowers the policy rate more aggressively, resulting in higher volatility of the nominal interest rate. Despite the larger drop in activity, public debt varies little because fiscal policy remains unresponsive. In equilibrium, the sharper decline in consumption restores the equality between the marginal utilities of consumption and bond holdings, leading to higher volatility in both output and inflation.

Finally, the fiscal rule in which the fiscal authority keeps public debt constant (purple bars in Figure 5) can be viewed as an extreme version of the rule described above (yellow bars). It generates the same underlying mechanism but amplifies it, resulting in much larger volatility of the output gap, inflation, and the nominal interest rate, while public debt remains fixed by construction.

To sum up, this exercise yields three main insights. First, in our DSGE model—where divine coincidence does not hold because of the various nominal and real frictions—it remains optimal for the monetary authority to target the natural rate. Second, the interaction between fiscal and monetary policy plays a central role in amplifying business-cycle fluctuations. Finally, the results indicate that, regardless of the fiscal authority's objectives, it is preferable for fiscal policy to respond to interest-rate movements: failing to do so does not mitigate the volatility of the output gap, inflation, the nominal interest rate, or public debt.

6 Conclusions

We document a new empirical fact: when the U.S. public debt-to-GDP ratio increases, the Federal Reserve tends to lower the policy rate. We propose an explanation for this finding: public debt conveys information about the natural rate of interest, and the Federal Reserve responds to that information rather than to debt itself. To account for this mechanism, we develop a model in which the level of debt and the natural rate are jointly determined. In the model, shocks to households' demand for government bonds—interpreted as liquidity or safety shocks—generate a negative comovement between debt and the natural rate, consistent with the empirical evidence.

We corroborate this explanation both empirically and quantitatively. Empirically, we construct a debt-informed measure of the natural rate and show that, once this measure is included in the Taylor rule, the response of monetary policy to debt disappears: the Federal Reserve reacts to the natural rate rather than to debt itself. Quantitatively, our estimated DSGE model shows that liquidity shocks—capturing shifts in households' demand for government bonds—account for a large share of business-cycle fluctuations and reproduce the observed negative comovement between debt and the natural rate over 1980–2019. Taken together, the empirical and quantitative evidence point to the same conclusion: monetary policy does not respond to debt itself, but to the information that debt conveys about the natural rate.

While the mechanism explains the typical negative relationship between public debt and the natural rate, the analysis also clarifies when this relationship may invert. If debt increases because of expansionary fiscal policy—through higher government spending or lower taxes—the natural rate rises, prompting the Federal Reserve to raise, rather than cut, the policy rate. An apparently accommodative response to debt therefore reflects the nature of the underlying shocks, not a systematic fiscal accommodation.

Overall, public debt, the natural rate, and nominal interest rates are tightly linked. Their joint dynamics depend on whether demand or fiscal forces dominate the business cycle, and debt provides valuable information for inferring the natural rate—an unobservable but central object for monetary policy. When public debt rises for fiscal reasons, both the natural rate and the policy rate increase, implying that monetary policy may tighten rather than ease in response to higher debt.

Finally, the paper opens several avenues for future research. First, our model assumes that the Federal Reserve perfectly observes the natural rate, whereas in reality this variable is unobservable. Allowing for partial information could provide valuable insights into how the natural rate is inferred and how informative public debt and other variables are about its movements. Second, our framework can be used to study optimal fiscal–monetary interactions—how policy design and coordination affect business-cycle dynamics. We leave these questions for future research.

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APPENDIX

Why the Federal Reserve Cuts Rates when Public Debt Rises

Andrea Ferrara & Luca Zanotti

A Empirical Robustness Checks

Table A.1: Taylor rule estimates using the GDP deflator instead of the CPI

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{GDP}	1.29***	1.85***	1.93***	1.60***	1.15***
	0.389	0.569	0.403	0.401	0.211
y_t	0.71***	0.81***	1.00***	0.86***	0.56***
	0.244	0.243	0.232	0.213	0.118
d_t	-0.82***	-0.69**	-0.40*	-0.58***	-1.02***
	0.269	0.266	0.238	0.226	0.116
ρ	0.76***	0.86***	0.84***	0.86***	0.76***
	0.093	0.035	0.030	0.0361	0.037
N	162	159	162	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are inflation, constructed using the GDP deflator, π_t, the output gap, y_t, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit equals 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.2: Taylor rule estimates using PCE inflation instead of CPI

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{PCE}	1.60***	2.17***	2.10***	2.01***	1.45***
	0.330	0.280	0.235	0.279	0.163
y_t	0.78***	1.12***	1.06***	1.16***	0.60***
	0.190	0.176	0.149	0.184	0.082
d_t	-0.59***	-0.25	-0.26*	-0.21	-0.84***
	0.228	0.171	0.149	0.171	0.091
ρ	0.68***	0.77***	0.74***	0.79***	0.67***
	0.100	0.038	0.033	0.040	0.040
N	162	159	162	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are PCE inflation, π_t, the output gap, y_t, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit equals 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.3: Taylor rule estimates without using the Wu and Xia (2016) shadow rate

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	1.17***	1.20***	1.25***	1.08***	1.33***
	0.235	0.198	0.143	0.197	0.127
y_t	0.47***	0.55***	0.59***	0.62***	0.41***
	0.173	0.140	0.109	0.133	0.092
d_t	-0.62***	-0.54***	-0.48***	-0.54***	-0.57***
	0.182	0.129	0.113	0.128	0.073
ρ	0.66***	0.75***	0.68***	0.76***	0.66***
	0.113	0.051	0.032	0.048	0.029
N	162	159	162	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t, and, unlike in the baseline specification, it is not replaced by the Wu and Xia (2016) shadow rate for the period from 2009:Q1 to 2015:Q4. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit equals 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.4: Taylor rule estimates for the pre-zero lower bound period

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	0.85***	0.83***	1.01***	0.72***	1.12***
	0.232	0.204	0.160	0.190	0.0919
y_t	0.43***	0.50***	0.51***	0.55***	0.38***
	0.162	0.136	0.117	0.125	0.071
d_t	-1.35***	-1.24***	-1.06***	-1.36***	-1.29***
	0.256	0.179	0.197	0.237	0.097
ρ	0.58***	0.70***	0.61***	0.69***	0.56***
	0.139	0.064	0.053	0.056	0.041
N	130	130	130	130	128

Notes: The table reports estimates of equation (1) over a shortened sample ending in 2011:Q3, when the zero lower bound became binding. The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit equals 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.5: Taylor rule estimates using the ratio of debt at time t to GDP at time $t-1$

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	1.19***	1.11***	1.30***	1.20***	1.18***
	0.253	0.226	0.170	0.219	0.121
y_t	0.61***	0.73***	0.84***	0.82***	0.44***
	0.196	0.172	0.159	0.161	0.085
d_t	-0.72***	-0.80***	-0.55***	-0.60***	-0.96***
	0.219	0.177	0.158	0.175	0.082
ρ	0.68***	0.76***	0.72***	0.77***	0.61***
	0.105	0.051	0.032	0.044	0.041
N	162	159	162	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and ratio of public debt at time t to GDP at time $t-1$, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit equals 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.6: Taylor rule estimates using the ratio of debt to potential GDP

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	1.21***	1.17***	1.34***	1.26***	1.21***
	0.254	0.227	0.169	0.219	0.121
y_t	0.67***	0.80***	0.91***	0.89***	0.50***
	0.191	0.169	0.160	0.159	0.084
d_t	-0.71***	-0.76***	-0.52***	-0.54***	-0.97***
	0.223	0.183	0.159	0.172	0.084
ρ	0.69***	0.77***	0.73***	0.78***	0.63***
	0.102	0.049	0.030	0.043	0.039
N	162	159	162	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and the ratio of public debt to potential GDP, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit equals 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.7: Taylor rule estimates using inflation and output gap at time $t+1$

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_{t+1}	1.51***	1.46***	1.63***	1.40***	1.57***
	0.301	0.183	0.149	0.213	0.131
y_{t+1}	0.63***	0.81***	0.79***	0.90***	0.40***
	0.189	0.155	0.126	0.161	0.0661
d_t	-0.59***	-0.58***	-0.44***	-0.56***	-0.96***
	0.200	0.145	0.131	0.144	0.0570
ρ	0.70***	0.74***	0.73***	0.78***	0.62***
	0.0779	0.0375	0.0275	0.0358	0.0263
N	162	159	162	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_{t+1}, the output gap, y_{t+1}, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit equals 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.8: Cumby and Huizinga (1992) serial correlation test

	OLS	GMM	GMM BC	GMM EBP	GMM Shocks
1	.663032	.15767081	.76816332	.3089788	.51267922
2	.19741714	.28116834	.60089999	.4939456	.68518537
3	.0949613	.25288606	.32278278	.30565879	.45888889
4	.16842528	.38381499	.44401005	.45868069	.61083186

Notes: Each row j reports the Cumby and Huizinga (1992) test statistic for serial correlation in the residuals under the null that all autocorrelation coefficients up to j are zero. Each column corresponds to the respective specification in Table 1.

Table A.9: Taylor rule estimates using filtered variables

	(1) Benchmark	(2) OLS HP	(3) GMM HP	(4) OLS Ham	(5) GMM Ham
π_t^{cpi}	0.65***	0.37***	0.44***	0.59***	0.42***
	0.140	0.124	0.047	0.144	0.061
y_t	0.27***	0.23*	0.31***	0.26	0.27***
	0.089	0.117	0.048	0.186	0.058
d_t	-0.41***	-0.26**	-0.13***	-0.30*	-0.27***
	0.120	0.129	0.049	0.172	0.049
ρ	0.69***	0.31***	0.33***	0.59***	0.45***
	0.106	0.101	0.024	0.095	0.034
N	162	162	143	162	143

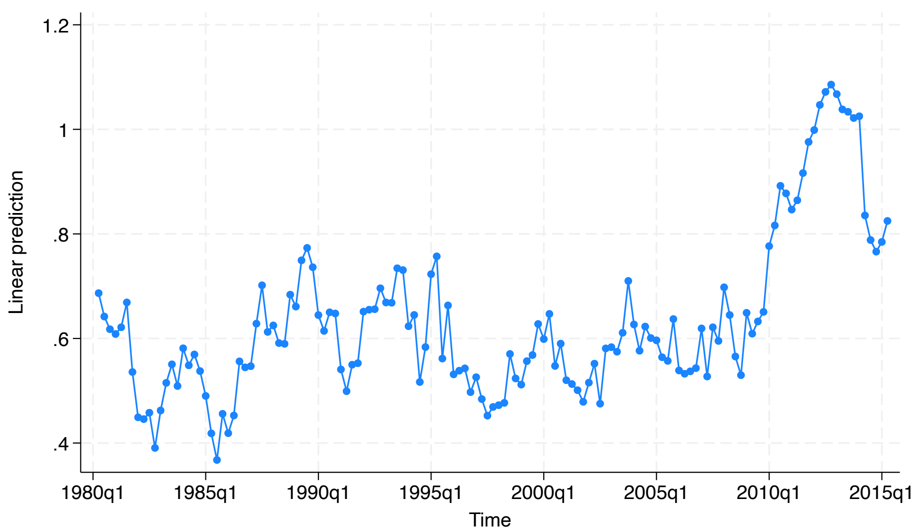
Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_{t+1}, the output gap, y_{t+1}, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. All variables are standardized by their respective standard deviations. Column (1) reports OLS estimates when the variables are in levels. Columns (2) and (3) report OLS and GMM estimates when all variables are detrended using the one-sided Hodrick and Prescott (1997) filter. Columns (4) and (5) report OLS and GMM estimates when all variables are detrended using the Hamilton (2018) filter. Columns (3) and (5) use as instruments lags 5 through 20 of the business-cycle shock of Angeletos, Collard, and Dellas (2020), the excess bond premium shock of Gilchrist and Zakrajšek (2012), the government spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.10: Taylor rule estimates using filtered variables without lagged nominal rate

	(1) Benchmark	(2) OLS HP	(3) GMM HP	(4) OLS Ham	(5) GMM Ham
π_t^{cpi}	0.42***	0.37***	0.42***	0.52***	0.33***
	0.083	0.105	0.029	0.066	0.049
y_t	0.08	0.10	0.16***	0.03	0.16**
	0.063	0.107	0.045	0.156	0.067
d_t	-0.59***	-0.42***	-0.34***	-0.42***	-0.39***
	0.089	0.106	0.035	0.144	0.054
N	162	162	143	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_{t+1}, the output gap, y_{t+1}, and the public debt-to-GDP ratio, d_t. All variables are standardized by their respective standard deviations. Column (1) reports OLS estimates when the variables are in levels. Columns (2) and (3) report OLS and GMM estimates when all variables are detrended using the one-sided Hodrick and Prescott (1997) filter. Columns (4) and (5) report OLS and GMM estimates when all variables are detrended using the Hamilton (2018) filter. Columns (3) and (5) use as instruments lags 5 through 20 of the business-cycle shock of Angeletos, Collard, and Dellas (2020), the excess bond premium shock of Gilchrist and Zakrajšek (2012), the government spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Figure A.1: First stage of the debt-to-GDP ratio using only macroeconomic shocks



Notes: The figure shows the first-stage fitted values of the public debt-to-GDP ratio corresponding to column (5) in Table 1, where only macroeconomic shocks are used as instruments.

Table A.11: Taylor rule estimates using the system-projections instrumental-variables method

Variables	**coeffs**
π_t	0.73
	(0.304)
y_t	0.59
	(0.223)
d_t	-1.28
	(0.428)
ρ	0.643
	(0.088)

Notes: The table reports estimates of equation (1) using the system-projections instrumental-variables method of Lewis and Mertens (2022). The dependent variable is the federal funds rate, r_t. The explanatory variables are PCE inflation, π_t, the output gap, y_t, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. The instruments are the shocks of Angeletos, Collard, and Dellas (2020), Gilchrist and Zakrajšek (2012), Ramey (2016), and Känzig (2021).

Table A.12: Taylor rule estimates using average realized values of inflation and output

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
$\sum_{j=0}^{4} \pi_{t+j}$	1.67***	1.71***	1.91***	1.89***	1.63***
	0.475	0.232	0.213	0.250	0.174
$\sum_{j=0}^{4} y_{t+j}$	0.66**	0.98***	0.99***	1.03***	0.35***
	0.269	0.189	0.171	0.171	0.096
d_t	-0.54*	-0.47***	-0.33**	-0.26*	-0.99***
	0.288	0.170	0.161	0.160	0.085
ρ	0.72***	0.78***	0.76***	0.80***	0.65***
	0.085	0.034	0.030	0.027	0.041
N	162	159	162	162	143

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are the average of CPI inflation over the current and next four quarters, $\sum_{j=0}^{4} \pi_{t+j}$, the average of the output gap over the current and next four quarters, $\sum_{j=0}^{4} y_{t+j}$, and the public debt-to-GDP ratio, d_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.13: Taylor rule estimates using average expected values of inflation and output

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
$\sum_{j=1}^{4} \pi_{t+j}^{GB}$	1.39***	1.27***	1.38***	1.23***	0.79***
	0.232	0.218	0.182	0.190	0.120
$\sum_{j=1}^{4} y_{t+j}^{GB}$	0.53***	0.48***	0.50***	0.54***	0.52***
	0.089	0.088	0.060	0.052	0.043
d_t	-0.65***	-0.71***	-0.65***	-0.70***	-0.78***
	0.130	0.085	0.087	0.078	0.052
ρ	0.81***	0.85***	0.83***	0.83***	0.80***
	0.031	0.019	0.016	0.021	0.011
N	122	122	122	122	113

Notes: The table reports estimates of equation (1). The dependent variable is the federal funds rate, r_t. The explanatory variables are the average of expected CPI inflation over the next four quarters, $\sum_{j=1}^{4} \pi_{t+j}^{GB}$, the average of the expected output gap over the next four quarters, $\sum_{j=1}^{4} y_{t+j}^{GB}$, and the public debt-to-GDP ratio, d_t. Expectations data are taken from the Greenbook. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.14: Taylor rule estimates controlling for the realized values of inflation and the output gap three years ahead

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.01***	1.12***	1.21***	1.05***	1.11***
	0.235	0.233	0.256	0.278	0.116
y_t	0.57***	0.71***	0.74***	0.59***	0.46***
	0.175	0.144	0.142	0.155	0.0870
d_t	-0.78***	-0.64***	-0.65***	-0.63***	-0.94***
	0.191	0.159	0.161	0.193	0.0908
π_{t+12}	0.40**	0.59**	0.16	0.72*	0.38*
	0.175	0.231	0.320	0.419	0.212
y_{t+12}	-0.07	0.22	0.14	0.26	-0.10
	0.180	0.242	0.190	0.247	0.0932
ρ	0.65***	0.73***	0.71***	0.71***	0.58***
	0.117	0.0478	0.0416	0.0623	0.0462
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the realized values of inflation and the output gap three years ahead, π_{t+12} and y_{t+12}. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.15: Taylor rule estimates controlling for the realized values of inflation and the output gap five years ahead

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	0.95***	0.75***	0.89***	0.95***	1.13***
	0.242	0.189	0.153	0.246	0.117
y_t	0.54***	0.67***	0.63***	0.78***	0.50***
	0.169	0.126	0.109	0.165	0.074
d_t	-0.89***	-0.87***	-0.84***	-0.80***	-0.85***
	0.192	0.142	0.138	0.161	0.064
π_{t+20}	0.48***	0.77***	0.56***	0.42	0.64***
	0.166	0.214	0.157	0.275	0.111
y_{t+20}	-0.05	0.13	0.22	-0.09	-0.27***
	0.157	0.165	0.166	0.248	0.057
ρ	0.62***	0.68***	0.60***	0.76***	0.56***
	0.129	0.056	0.049	0.049	0.043
N	156	156	156	156	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the realized values of inflation and the output gap five years ahead, π_{t+20} and y_{t+20}. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.16: Taylor rule estimates controlling for the realized values of inflation and the output gap ten years ahead

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	0.89***	0.94***	1.03***	1.10***	1.21***
	0.267	0.240	0.233	0.273	0.104
y_t	0.38***	0.54***	0.67***	0.68***	0.33***
	0.138	0.136	0.148	0.186	0.082
d_t	-1.17***	-1.07***	-0.93***	-0.92***	-0.93***
	0.262	0.215	0.226	0.250	0.080
π_{t+40}	-0.02	0.14	0.17	-0.20	-0.07
	0.207	0.278	0.291	0.283	0.063
y_{t+40}	0.15	-0.02	0.03	-0.22	0.18**
	0.146	0.163	0.120	0.191	0.089
ρ	0.58***	0.71***	0.68***	0.76***	0.61***
	0.127	0.055	0.048	0.050	0.037
N	136	136	136	136	134

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the realized values of inflation and the output gap ten years ahead, π_{t+40} and y_{t+40}. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.17: Taylor rule estimates controlling for Drechsel (2024)'s number of interactions between the U.S. president and the Federal Reserve chair

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.08***	1.42***	1.35***	1.41***	1.17***
	0.254	0.179	0.198	0.156	0.124
y_t	0.46**	0.43***	0.52***	0.42***	0.44***
	0.187	0.097	0.109	0.107	0.087
d_t	-0.99***	-0.84***	-0.83***	-1.00***	-0.97***
	0.237	0.122	0.182	0.150	0.085
# interactions$_t$	-0.24	-1.09***	-0.80***	-1.47***	0.06
	0.263	0.343	0.215	0.388	0.111
ρ	0.62***	0.58***	0.60***	0.59***	0.62***
	0.135	0.064	0.052	0.068	0.043
N	150	150	150	150	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the number of interactions—phone calls and in-person meetings—between the U.S. president and the Federal Reserve chair, # interactions$_t$, taken from Drechsel (2024). The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.18: Taylor rule estimates controlling for the distance to the next election

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.18***	1.18***	1.27***	1.24***	1.18***
	0.252	0.182	0.170	0.187	0.115
y_t	0.61***	0.72***	0.86***	0.81***	0.42***
	0.196	0.156	0.165	0.150	0.0897
d_t	-0.74***	-0.78***	-0.57***	-0.59***	-0.95***
	0.219	0.165	0.158	0.168	0.0848
Dist. to elec.$_t$	0.18	0.17	0.20	0.25	0.37***
	0.296	0.154	0.161	0.153	0.0915
ρ	0.68***	0.74***	0.73***	0.77***	0.62***
	0.107	0.0482	0.0315	0.0418	0.0417
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the number of quarters until the next midterm or presidential election, Dist. to elec.$_t$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.19: Taylor rule estimates controlling for NBER recession dates

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.40***	1.47***	1.44***	1.55***	1.35***
	0.264	0.216	0.178	0.242	0.139
y_t	0.44**	0.55***	0.59***	0.60***	0.40***
	0.199	0.148	0.142	0.168	0.074
d_t	-0.78***	-0.79***	-0.74***	-0.80***	-1.01***
	0.208	0.151	0.144	0.145	0.079
NBER rec.$_t$	-1.557**	-1.796***	-1.776***	-2.122***	-0.901**
	0.501	0.346	0.289	0.358	0.275
ρ	0.72***	0.78***	0.75***	0.81***	0.64***
	0.097	0.048	0.034	0.043	0.040
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and a dummy variable for NBER recession dates, NBER rec.$_t$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.20: Taylor rule estimates controlling for BAA-AAA spread

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.20***	1.10***	1.26***	1.20***	1.17***
	0.246	0.223	0.177	0.201	0.120
y_t	0.53**	0.57***	0.75***	0.79***	0.52***
	0.244	0.199	0.204	0.186	0.090
d_t	-0.77***	-0.86***	-0.64***	-0.62***	-0.91***
	0.233	0.174	0.170	0.165	0.085
Baa-Aaa sp.$_t$	-0.58	-1.04	-0.49	-0.16	0.77***
	1.018	0.789	0.803	0.709	0.283
ρ	0.69***	0.79***	0.74***	0.77***	0.60***
	0.107	0.043	0.034	0.041	0.047
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the BAA-AAA spread, Baa-Aaa sp.$_t$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.21: Taylor rule estimates controlling for Gilchrist and Zakrajšek (2012) spread

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	0.99***	0.80***	0.79***	0.82***	1.14***
	0.220	0.197	0.170	0.195	0.118
y_t	0.48***	0.43***	0.48***	0.51***	0.42***
	0.169	0.113	0.120	0.129	0.075
d_t	-0.77***	-0.76***	-0.73***	-0.76***	-0.95***
	0.176	0.135	0.104	0.133	0.078
gz_t	-0.86**	-1.57***	-1.85***	-1.35***	-0.34**
	0.348	0.477	0.610	0.371	0.146
ρ	0.64***	0.68***	0.61***	0.70***	0.60***
	0.109	0.057	0.058	0.053	0.038
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the Gilchrist and Zakrajšek (2012) spread, gz_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.22: Taylor rule estimates controlling for NFCI

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.33***	1.37***	1.48***	1.44***	1.20***
	0.317	0.215	0.195	0.211	0.141
y_t	0.57***	0.63***	0.68***	0.75***	0.43***
	0.212	0.156	0.155	0.162	0.088
d_t	-0.75***	-0.72***	-0.61***	-0.53***	-0.97***
	0.225	0.159	0.149	0.137	0.083
NFCI_t	-0.54	-0.50	-0.68	-0.38	-0.04
	0.692	0.460	0.448	0.537	0.227
ρ	0.70***	0.73***	0.72***	0.75***	0.62***
	0.110	0.050	0.032	0.043	0.042
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the Chicago Fed National Financial Conditions Index, NFCI_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.23: Taylor rule estimates controlling for the CBOE Volatility Index

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	0.33	0.97***	0.70***	1.10***	0.54***
	0.409	0.363	0.181	0.225	0.053
y_t	0.91***	1.00***	0.86***	0.74***	0.79***
	0.249	0.156	0.144	0.128	0.049
d_t	-0.51**	-0.30**	-0.51***	-0.43***	-0.65***
	0.211	0.147	0.087	0.080	0.046
VIX_t	-0.16**	-0.08	-0.10***	-0.05	-0.05***
	0.067	0.057	0.036	0.037	0.010
ρ	0.89***	0.89***	0.86***	0.89***	0.84***
	0.024	0.018	0.021	0.018	0.012
N	120	113	116	116	103

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the CBOE Volatility Index, VIX_t. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1+\rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table A.24: Taylor rule estimates controlling for the S&P500 returns

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.18***	1.13***	1.30***	1.23***	1.18***
	0.249	0.223	0.176	0.218	0.123
y_t	0.60***	0.69***	0.81***	0.84***	0.44***
	0.197	0.138	0.133	0.158	0.086
d_t	-0.74***	-0.75***	-0.56***	-0.53***	-0.97***
	0.218	0.178	0.169	0.189	0.086
$\Delta\log(\text{S\&P500})_t$	-0.72	0.85	2.64	-5.63	0.43
	4.373	5.504	4.667	4.500	1.309
ρ	0.68***	0.76***	0.71***	0.78***	0.61***
	0.106	0.053	0.032	0.042	0.043
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the S&P500 returns, $\Delta\log(\text{S\&P 500})_t$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

B Stylized New Keynesian model

B.1 Model framework

The model features five agents: final-goods producers, intermediate-goods producers, households, and the fiscal and monetary authorities. The production sectors follow standard New Keynesian formulations. Below we describe the problem faced by each agent.

B.1.1 Final-goods producers

At each point in time t, perfectly competitive firms produce a homogeneous final good Y_t by aggregating a continuum of differentiated intermediate goods $Y_t(i)$, $i \in [0,1]$, according to $Y_t = \left[\int_0^1 Y_t(i)^{\frac{1}{1+\lambda_p}} di\right]^{1+\lambda_p}$. Profit maximization and the zero-profit condition imply that the price of the final good, P_t, is a CES aggregate of the prices of intermediate goods $P_t(i)$: $P_t = \left[\int_0^1 P_t(i)^{-\frac{1}{\lambda_p}} di\right]^{-\lambda_p}$. The corresponding demand for each intermediate variety i is then $Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\frac{1+\lambda_p}{\lambda_p}} Y_t$.

B.1.2 Intermediate-goods producers

Each intermediate good i is produced by a monopolistically competitive firm according to $Y_t(i) = L_t(i)^{1-\alpha}$ where $L_t(i)$ denotes the amount of labor employed by firm i. Following Calvo (1983), in each period a fraction ξ_p of firms cannot adjust their price, while the remaining fraction chooses $P_t(i)$ optimally to maximize the expected discounted value of future profits:

$$\mathbb{E}_t \left\{ \sum_{s=0}^{\infty} \xi_p^s \beta^s \frac{\Lambda_{t+s}}{\Lambda_t} \left[P_t(i) Y_{t+s}(i) - W_{t+s} L_{t+s}(i) \right] \right\} \tag{7}$$

subject to the demand function and cost-minimization conditions. In this expression, Λ_t denotes the marginal utility of nominal income of the representative household that owns the firm, and W_t is the nominal wage.

B.1.3 Household

The representative household maximizes expected lifetime utility:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \left[\log(C_{t+s}) - L_{t+s} + \phi_B (B_{t+s} - \eta_t B)^2 \right], \tag{8}$$

where C_t denotes aggregate consumption, B_t the real value of bond holdings, B its steady-state value, and η_t a shock to households' preference for holding bonds. We interpret this shock as a liquidity or safety shock, since in equilibrium household bond holdings correspond to government debt, which is both liquid and safe. The liquidity shock follows an AR(1) process:

$$\log(\eta_t) = (1-\rho_\eta)\eta + \rho_\eta \log(\eta_{t-1}) + \varepsilon_{\eta,t},$$

where η is the steady-state value. The household's nominal flow budget constraint is

$$P_t C_t + P_t B_t + P_t T_t \leq R_{t-1} P_{t-1} B_{t-1} + W_t L_t + \Pi_t,$$

where T_t denotes lump-sum taxes, Π_t profits from firm ownership, and the aggregate consumption index is

$$C_t = \left(\int_0^1 C_t(i)^{\frac{1}{1+\lambda_p}}, di \right)^{1+\lambda_p}.$$

B.1.4 The government and market clearing

The monetary authority sets the nominal interest rate according to a feedback rule of the form

$$\frac{R_t}{R} = \left(\frac{R_t^*}{R}\right)^{\phi_{R^*}} \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{Y_t}{Y_t^*}\right)^{\phi_y} \tag{9}$$

where R denotes the steady-state gross nominal interest rate, $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is gross inflation, and π its steady-state value. Following the DSGE literature, variables with an asterisk * refer to the natural or flexible-price equilibrium—that is, the allocation that would prevail in the absence of nominal rigidities.

The novelty in equation (9) is the inclusion of the term $\left(\frac{R_t^*}{R}\right)^{\phi_{R^*}}$. This assumptions allows the monetary authority to target the natural rate, and it is important to reconcile our insight that debt is informative about the natural rate but the monetary authority is not reacting to it, but to the natural rate.

The government's flow budget constraint in real terms is

$$D_t = R_{t-1}\pi_t^{-1} D_{t-1} - T_t, \tag{10}$$

where D_t denotes the real value of government debt and T_t lump-sum taxes. We abstract from government purchases and assume that the government issues only short-term bonds.

Fiscal policy is non-Ricardian because bonds enter the household's utility function. It is therefore necessary to specify the tax rule followed by the fiscal authority, which we assume takes the form

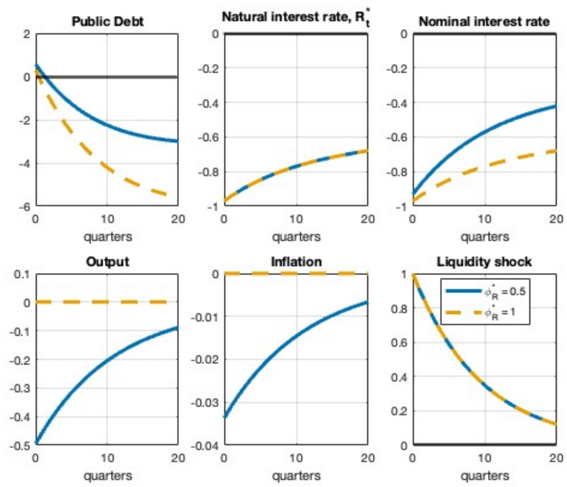
$$T_t - \tilde{T} = \tau_y Y_t + \tau_d D_{t-1} + \tau_R(R_t \pi_{t+1}^{-1}), \tag{11}$$

where $\tilde{T}$ is the steady-state level of tax revenues. The parameter τ_y captures the responsiveness of taxes to output fluctuations, τ_d governs how aggressively the government stabilizes debt, and τ_R measures the sensitivity of taxes to the real interest rate. The last term is novel relative to the standard literature and reflects the idea that issuing debt becomes more costly when interest rates rise, prompting the fiscal authority to increase tax revenues.

Finally, the aggregate resource constraint is $C_t = Y_t$, and the bond-market-clearing condition is $B_t = D_t$.

B.2 Impulse response function to a liquidity shock - robustness

Figure B.1: Impulse response functions to a liquidity shock - $\tau_R = 0.2$



Notes: The figure shows the impulse response functions to a one-standard-deviation liquidity (safety) shock that raises households' preference for holding government bonds. The blue line corresponds to the Taylor rule with $\phi_{R^*} = 0.5$, while the yellow line corresponds to the rule with $\phi_{R^*} = 1$. The panels display, in order, the responses of public debt, the natural rate of interest, the nominal interest rate, output, inflation, and the liquidity shock itself. The figure uses a small tax response to interest rate changes, $\tau_R = 0.2$.

C Robustness of the estimates on the natural rate

Table C.1: Taylor rule using the natural rate estimated by Laubach and Williams (2003)

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.17***	1.18***	1.24***	1.36***	1.19***
	0.250	0.192	0.178	0.215	0.117
y_t	0.63*	0.77***	0.98***	1.26***	0.63***
	0.376	0.257	0.312	0.317	0.092
d_t	-0.80	-0.81**	-0.85**	-1.09***	-1.58***
	0.500	0.398	0.357	0.353	0.152
$R_t^{*,lw}$	-0.18	-0.18	-0.72	-2.00*	-1.55***
	1.527	0.995	1.128	1.135	0.371
ρ	0.68***	0.74***	0.74***	0.79***	0.59***
	0.114	0.049	0.035	0.042	0.040
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the natural rate of interest estimated by Laubach and Williams (2003), $R_t^{*,lw}$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table C.2: Taylor rule using the natural rate estimated by Holston, Laubach, and Williams (2017)

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.17***	1.18***	1.27***	1.34***	1.22***
	0.252	0.194	0.180	0.206	0.126
y_t	0.70*	0.91***	1.13***	1.39***	0.60***
	0.366	0.301	0.330	0.361	0.098
d_t	-0.96*	-1.07***	-1.13***	-1.46***	-1.39***
	0.571	0.404	0.405	0.477	0.137
$R_t^{*,hlw}$	-0.54	-0.83	-1.46	-2.55*	-1.04***
	1.456	0.992	1.135	1.303	0.317
ρ	0.68***	0.75***	0.75***	0.79***	0.61***
	0.109	0.050	0.032	0.042	0.042
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and the natural rate of interest estimated by Holston, Laubach, and Williams (2017), $R_t^{*,hlw}$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

D Time-varying parameter VAR

D.1 TVP-VAR model

This section describes the time-varying parameter VAR following Primiceri (2005). The model is given by

$$y_t = c_t + B_{1,t}y_{t-1} + \cdots + B_{k,t}y_{t-k} + u_t \qquad t = 1, ..., T$$

where y_t is an $n \times 1$ vector of observable variables, c_t is an $n \times 1$ vector of time-varying coefficients on the constant terms, and $B_{i,t}$ $(i = 1, \ldots, k)$ are $n \times n$ matrices of time-varying coefficients. The residuals u_t are heteroskedastic structural shocks with variance–covariance matrix Ω_t, such that

$$A_t \Omega_t A_t' = \Sigma_t \Sigma_t',$$

where A_t is a lower triangular matrix

$$A_t = \begin{bmatrix} 1 & 0 & \cdots & 0 \\ \alpha_{21,t} & 1 & \cdots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ \alpha_{n1,t} & \cdots & \alpha_{n\,n-1,t} & 1 \end{bmatrix},$$

and Σ_t is a diagonal matrix of time-varying standard deviations:

$$\Sigma_t = \begin{bmatrix} \sigma_{1,t} & 0 & \cdots & 0 \\ 0 & \sigma_{2,t} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \sigma_{n,t} \end{bmatrix}.$$

The model can therefore be written as

$$y_t = c_t + B_{1,t}y_{t-1} + \cdots + B_{k,t}y_{t-k} + A_t^{-1}\Sigma_t\varepsilon_t, \qquad \text{Var}(\varepsilon_t) = I_n$$

where I_n is the $n \times n$ identity matrix. Stacking all coefficients in the vector B_t, the system can be expressed as

$$\begin{cases} y_t = X_t' B_t + A_t^{-1}\Sigma_t\varepsilon_t, \\ X_t' = I_n \otimes [1, y_{t-1}', ..., y_{t-k}'], \end{cases}$$

where $\otimes$ denotes the Kronecker product.

The coefficients evolve according to random walks:

$$\begin{cases} B_t = B_{t-1} + \nu_t, \\ \alpha_t = \alpha_{t-1} + \zeta_t, \\ \log \sigma_t = \log \sigma_{t-1} + \eta_t, \end{cases}$$

where ν_t, ζ_t, and η_t are mutually uncorrelated innovations.

The joint variance–covariance matrix of the innovations is block-diagonal:

$$V = \text{Var}\left(\begin{bmatrix} \varepsilon_t \\ \nu_t \\ \zeta_t \\ \eta_t \end{bmatrix}\right) = \begin{bmatrix} I_n & 0 & 0 & 0 \\ 0 & Q & 0 & 0 \\ 0 & 0 & S & 0 \\ 0 & 0 & 0 & W \end{bmatrix},$$

where S is block diagonal, with each block corresponding to the contemporaneous parameters of a given equation (so that these coefficients evolve independently across equations).

Following Primiceri (2005), the priors are specified as:

$$\begin{aligned} B_0 &\sim \mathcal{N}(\hat{B}_{OLS},\, 4 \cdot \text{Var}(\hat{B}_{OLS})), \\ A_0 &\sim \mathcal{N}(\hat{A}_{OLS},\, 4 \cdot \text{Var}(\hat{A}_{OLS})), \\ \log \sigma_0 &\sim \mathcal{N}(\log \hat{\sigma}_{OLS},\, I_n), \\ Q &\sim \mathcal{IW}(k_Q^2 \cdot 40 \cdot \text{Var}(\hat{B}_{OLS}),\, 40), \\ W &\sim \mathcal{IW}(k_W^2 \cdot 4 \cdot I_n,\, 4), \\ S_1 &\sim \mathcal{IW}(k_S^2 \cdot 2 \cdot \text{Var}(\hat{A}_{1,OLS}),\, 2), \\ S_2 &\sim \mathcal{IW}(k_S^2 \cdot 3 \cdot \text{Var}(\hat{A}_{2,OLS}),\, 3), \\ S_3 &\sim \mathcal{IW}(k_S^2 \cdot 4 \cdot \text{Var}(\hat{A}_{3,OLS}),\, 4) \end{aligned}$$

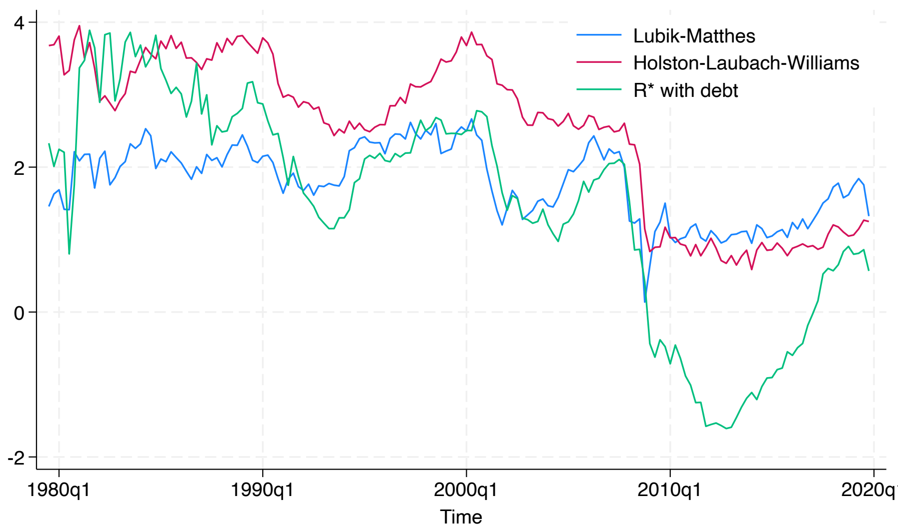
where $\hat{B}_{OLS}$, $\hat{A}_{OLS}$, and $\hat{\sigma}_{OLS}$ are the OLS estimates. S_1, S_2, and S_3 denote the corresponding blocks of S, and $\hat{A}i, OLS$ the analogous blocks of $\hat{A}_{OLS}$. As in Primiceri (2005), we set $k_Q = k_W = 0.01$ and $k_S = 0.1$. We use a ten-year training sample starting in 1961:Q1 and include only one lag ($p = 1$), given the large number of parameters induced by the inclusion of an additional variable.

The model features three sources of time variation: (i) the time variation in the lag coefficients of the model (captured by the innovation term ν_t in the random walk process for B_t), (ii) the time variation in the simultaneous response of variable j to variable i (captured by the innovation term ζ_t in the random walk process α_t), and (iii) the time variation in the variances of the shocks (captured by the innovation term η_t in the geometric random walk process for σ_t).

The model is estimated using Bayesian methods via a Gibbs sampler, a specific type of Markov Chain Monte Carlo (MCMC) algorithm. We run 1,000 iterations, discarding the first 200 as burn-in. Conditional forecasts are obtained by keeping coefficients fixed at each point in time.[22]

D.2 TVP-VAR results

Figure D.1: Different measures of the natural rate of interest



Notes: The figure shows in green our estimates of the natural rate, in blue those of Lubik and Matthes (2015), and in red those of Holston, Laubach, and Williams (2017).

[22] Allowing the coefficients to vary over time yields a correlation of 98.9% with our baseline measure.

Table D.1: Taylor rule estimates using our debt-informed natural rate measure and PCE inflation

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{pce}	1.00***	1.15***	1.10***	1.13***	0.78***
	0.299	0.204	0.213	0.188	0.123
y_t	0.28	0.32**	0.30**	0.33**	0.17***
	0.204	0.150	0.148	0.145	0.064
d_t	-0.18	-0.02	-0.06	-0.05	-0.18
	0.156	0.082	0.071	0.076	0.113
$R_t^{*,d}$	0.92***	0.97***	0.96***	0.95***	1.00***
	0.281	0.169	0.161	0.170	0.132
ρ	0.42	0.45***	0.44***	0.45***	0.37***
	0.274	0.120	0.122	0.115	0.099
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are PCE inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and our estimate of the natural rate of interest, $R_t^{*,d}$, constructed using PCE inflation instead of CPI inflation in the TVP-VAR. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table D.2: Taylor rule estimates based on our debt-informed natural rate measure constructed with the nominal rate in the TVP-VAR

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	0.47***	0.45***	0.49***	0.47***	0.70***
	0.127	0.073	0.063	0.101	0.122
y_t	0.13	0.10*	0.12*	0.14*	0.25***
	0.091	0.050	0.059	0.085	0.074
d_t	0.12	0.17**	0.10	0.07	-0.34**
	0.117	0.0795	0.0877	0.101	0.153
$R_t^{*,d}$	1.79***	1.82***	1.74***	1.69***	1.05***
	0.207	0.114	0.133	0.189	0.232
ρ	0.10	0.01	0.01	0.22	0.39***
	0.371	0.178	0.155	0.191	0.091
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are PCE inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and our estimate of the natural rate of interest, $R_t^{*,d}$, constructed using the nominal interest rate instead of the real rate in the TVP-VAR. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1+\rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table D.3: Taylor rule estimates using our debt-informed natural rate measure constructed with two lags in the TVP-VAR

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{cpi}	1.20***	1.15***	1.22***	1.17***	1.19***
	0.195	0.145	0.104	0.122	0.121
y_t	0.27	0.21**	0.26**	0.24**	0.42***
	0.173	0.102	0.106	0.107	0.0948
d_t	-0.16	-0.02	-0.07	-0.03	-0.90***
	0.201	0.117	0.122	0.119	0.156
$R_t^{*,d}$	1.09***	1.25***	1.15***	1.23***	0.08
	0.266	0.166	0.178	0.174	0.173
ρ	0.60***	0.58***	0.56***	0.60***	0.61***
	0.127	0.065	0.043	0.052	0.041
N	162	159	162	162	143

Notes: The table reports estimates of equation (2). The dependent variable is the federal funds rate, r_t. The explanatory variables are PCE inflation, π_t, the output gap, y_t, the public debt-to-GDP ratio, d_t, and our estimate of the natural rate of interest, $R_t^{*,d}$, constructed using two lags instead of one lag in the TVP-VAR. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. The variable d_t is rescaled so that one unit corresponds to 10 percentage points. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020) and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table D.4: Taylor rule estimates excluding public debt and using our debt-informed natural rate measure with PCE inflation

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t^{pce}	1.01***	1.26***	1.14***	1.22***	0.71***
	0.289	0.234	0.215	0.225	0.108
y_t	0.25	0.36**	0.33**	0.39**	0.12**
	0.193	0.167	0.156	0.176	0.058
$R_t^{*,d}$	1.07***	0.94***	1.01***	0.92***	1.18***
	0.212	0.174	0.151	0.176	0.061
ρ	0.41	0.49***	0.43***	0.51***	0.32***
	0.274	0.118	0.121	0.111	0.103
N	162	159	162	162	143

Notes: The table reports estimates of equation (1), where the debt-to-GDP ratio is replaced with our debt-informed measure of the natural rate of interest, $R_t^{*,d}$, constructed using PCE inflation instead of CPI inflation in the TVP-VAR. The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and our estimate of the natural rate of interest, $R_t^{*,d}$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1 - \rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020), and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table D.5: Taylor rule estimates excluding public debt and using our debt-informed natural rate measure constructed with the nominal rate in the TVP-VAR

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	0.51***	0.48***	0.53***	0.50***	0.54***
	0.138	0.096	0.078	0.108	0.081
y_t	0.15	0.15**	0.17***	0.18**	0.18***
	0.097	0.065	0.059	0.077	0.053
$R_t^{*,d}$	1.61***	1.59***	1.57***	1.57***	1.53***
	0.146	0.097	0.087	0.115	0.061
ρ	0.18	0.20	0.13	0.31**	0.25***
	0.331	0.157	0.127	0.149	0.087
N	162	159	162	162	143

Notes: The table reports estimates of equation (1), where the debt-to-GDP ratio is replaced with our debt-informed measure of the natural rate of interest, $R_t^{*,d}$, constructed using the nominal interest rate instead of the real rate in the TVP-VAR. The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and our estimate of the natural rate of interest, $R_t^{*,d}$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1+\rho_2$, so that they represent long-run effects. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020), and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table D.6: Taylor rule estimates excluding public debt and using our debt-informed natural rate measure constructed with two lags in the TVP-VAR

	(1) OLS	(2) GMM	(3) GMM BC	(4) GMM EBP	(5) GMM Shocks
π_t	1.26***	1.16***	1.26***	1.19***	1.42***
	0.164	0.120	0.0755	0.102	0.121
y_t	0.26	0.21**	0.24**	0.23**	0.33***
	0.178	0.103	0.099	0.103	0.103
$R_t^{*,d}$	1.26***	1.26***	1.24***	1.27***	0.98***
	0.203	0.136	0.114	0.131	0.085
ρ	0.61***	0.58***	0.57***	0.60***	0.67***
	0.121	0.063	0.040	0.051	0.031
N	162	159	162	162	143

Notes: The table reports estimates of equation (1), where the debt-to-GDP ratio is replaced with our debt-informed measure of the natural rate of interest, $R_t^{*,d}$, constructed using two lags instead of one lag in the TVP-VAR. The dependent variable is the federal funds rate, r_t. The explanatory variables are CPI inflation, π_t, the output gap, y_t, and our estimate of the natural rate of interest, $R_t^{*,d}$. The specification also includes two lags of the policy rate, r_{t-1} and r_{t-2}, with coefficients ρ_1 and ρ_2. All coefficients are rescaled by $1-\rho$, where $\rho \equiv \rho_1 + \rho_2$, so that they represent long-run effects. Column (1) reports OLS estimates. Column (2) reports GMM estimates using the instrument set of Clarida, Gali, and Gertler (2000), which includes lagged variables. Columns (3) and (4) use four lags of the explanatory variables as instruments and additionally include, respectively, the main business-cycle shock of Angeletos, Collard, and Dellas (2020), and the excess bond-premium shock of Gilchrist and Zakrajšek (2012). Column (5) uses only lagged macroeconomic shocks as instruments: the business-cycle shock, the excess bond-premium shock, the government-spending shock of Ramey (2016), and the news oil-price shocks of Känzig (2021). In columns (3)–(5), all shocks are used as instruments with lags 5 through 20. Newey–West standard errors with four lags are reported. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

E DSGE model

E.1 Decision problem of final goods producers, intermediate firms and Employment Agencies

E.1.1 Final goods producers

At each point in time t, the final consumption good Y_t is produced by a representative, perfectly competitive firm that aggregates a continuum of intermediate goods $Y_t(i)$, $i \in [0,1]$, according to a CES technology:

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{1}{1+\lambda_{p,t}}} \, di \right)^{1+\lambda_{p,t}}$$

The elasticity parameter $\lambda_{p,t}$ evolves according to the exogenous stochastic process

$$\log(1+\lambda_{p,t}) = (1-\rho_p)\log(1+\lambda_p) + \rho_p \log(1+\lambda_{p,t-1}) + \epsilon_{p,t} - \theta_p \epsilon_{p,t-1}.$$

where $\varepsilon_{p,t} \overset{i.i.d.}{\sim} \mathcal{N}(0, \sigma_p^2)$ represents a price-markup shock, since $\lambda_{p,t}$ captures the desired markup of prices over marginal cost for intermediate firms. The ARMA(1,1) structure allows the model to capture the moving-average, high-frequency component of inflation.

Each firm chooses $Y_t(i)_{i\in[0,1]}$ to minimize total cost, taking as given the prices $P_t(i)$ of intermediate goods, subject to the aggregation constraint above. The resulting demand for intermediate good i is

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\frac{1+\lambda_{p,t}}{\lambda_{p,t}}} Y_t,$$

where P_t is the final-goods price index:

$$P_t = \left(\int_0^1 P_t(i)^{-\frac{1}{\lambda_{p,t}}} \, di \right)^{-\lambda_{p,t}}. \tag{12}$$

E.1.2 Intermediate firms

Each intermediate-good producer i operates under monopolistic competition and produces output according to

$$Y_t(i) = \max\{A_t^{1-\alpha} K_t(i)^\alpha L_t(i)^{1-\alpha} - A_t F, 0\}.$$

where $K_t(i)$ and $L_t(i)$ denote the amounts of capital and labor employed by firm i. The parameter F represents a fixed cost of production, chosen so that profits are zero in the steady state (Christiano, Eichenbaum, and Evans, 2005).

The aggregate technology level A_t follows the stochastic process

$$\Delta log(A_t) \equiv z_t = (1-\rho_z)\gamma + \rho_z z_{t-1} + \epsilon_{z,t}, \qquad \epsilon_{z,t} \overset{i.i.d.}{\sim} \mathcal{N}(0, \sigma_z^2)$$

where $\varepsilon_{z,t}$ is a neutral technology shock. Technology is non-stationary, and its growth rate z_t evolves as an AR(1) process.

As in Calvo (1983), in each period a fraction ξ_p of firms cannot reoptimize their prices and instead follows the indexation rule

$$P_t(i) = \pi_{t-1}^{\iota_p} \pi^{1-\iota_p},$$

where $\pi_t \equiv \frac{P_t}{P_{t-1}}$ denotes gross inflation and π its steady-state value. The remaining fraction of firms reoptimizes prices to maximize the expected discounted value of future profits:

$$E_t \left\{ \sum_{s=0}^{\infty} \frac{\beta^s \Lambda_{t+s}}{\Lambda_t} \left[P_t(i) \left(\prod_{k=1}^{s} \pi_{t+k-1}^{\iota_p} \pi^{1-\iota_p} \right) Y_{t+s}(i) - W_{t+s} L_{t+s}(i) - r_{t+s}^k K_{t+s}(i) \right] \right\}$$

subject to the demand function in equation (12) and the firm's cost-minimization conditions. Here, Λ_t denotes the marginal utility of nominal income for the representative household that owns the firm, and W_t and r_t^k are the nominal wage and rental rate of capital, respectively.

E.1.3 Employment agencies

Firms are owned by a continuum of households indexed by $j \in [0, 1]$. Each household is a monopolistic supplier of specialized labor $L_t(j)$, as in Erceg, Henderson, and Levin (2000). A large number of competitive *employment agencies* aggregate this differentiated labor into a homogeneous labor input sold to intermediate firms, according to

$$L_t = \left[\int_0^1 L_t(j)^{1/(1+\lambda_{w,t})} dj \right]^{1+\lambda_{w,t}}.$$

As in the case of the final good, the desired wage markup $\lambda_{w,t}$—the markup of the nominal wage over the household's marginal rate of substitution—follows the exogenous stochastic process

$$\log(1+\lambda_{w,t}) = (1-\rho_w)\log(1+\lambda_w) + \rho_w \log(1+\lambda_{w,t-1}) + \varepsilon_{w,t} - \theta_w \varepsilon_{w,t-1},$$

where $\varepsilon_{w,t} \overset{i.i.d.}{\sim} \mathcal{N}(0, \sigma_w^2)$ represents the wage-markup shock.

Each perfectly competitive employment agency chooses L_t and $L_t(j)_{j\in[0,1]}$ to maximize profits, is:

$$\max_{L_t, L_t(j)} \quad W_t L_t - \int W_t(j) L_t(j) dj \qquad \textbf{s.t.} \qquad L_t = \left[\int_0^1 L_t(j)^{1/(1+\lambda_{w,t})} dj\right]^{1+\lambda_{w,t}}$$

The first-order conditions yield the labor demand for each type of worker:

$$L_t(j) = \left(\frac{W_t(j)}{W_t}\right)^{-(1+\lambda_{w,t})/\lambda_{w,t}} L_t,$$

where $W_t(j)$ denotes the nominal wage received by household j from the employment agencies. Imposing the zero-profit condition and substituting the labor demand yields the aggregate wage index:

$$W_t = \left[\int_0^1 W_t(j)^{-1/\lambda_{w,t}} dj\right]^{-\lambda_{w,t}}.$$

E.2 Data and observable variables

All the data are downloaded from FRED (Federal Reserve Economic Data).

The observable variables are constructed following Justiniano, Primiceri, and Tambalotti (2010). Real GDP is obtained by dividing nominal GDP by both the population (CNP16OV) and the GDP deflator (GDPDEF). Real consumption and real investment are constructed analogously. Consumption includes personal consumption expenditures on nondurable goods and services, while investment is defined as the sum of consumption expenditures on durables (CD) and private investment. The real wage is measured as hourly compensation in the nonfarm business sector for all workers (COMPNFB) divided by the GDP deflator. Hours worked are computed as total employment (CE160V) multiplied by average weekly hours of production workers (AWHNONAG), divided by the population. Inflation is measured as the quarterly log difference of the GDP deflator, and the nominal interest rate corresponds to the effective federal funds rate. Public debt is measured as the market value of gross federal debt (MVGFD027MNFRBDAL).

The observable variables, expressed in percentage terms, include the log differences of GDP, consumption, investment, and real wages, as well as inflation, the federal funds rate, hours worked, and the log of the public debt-to-GDP ratio. These variables are mapped to their model counterparts in the linearized system as follows:

$$\Delta(\log X_t^D) = \Delta \log\left(\frac{X_t^D}{A_t}\right) + \Delta \log(A_t) = 100 * (\hat{x}_t - \hat{x}_{t-1} + \hat{z}_t) + 100\gamma$$

$$\Delta(\log C_t^D) = \Delta \log\left(\frac{C_t^D}{A_t}\right) + \Delta \log(A_t) = 100 * (\hat{c}_t - \hat{c}_{t-1} + \hat{z}_t) + 100\gamma$$

$$\Delta(\log I_t^D) = \Delta \log\left(\frac{I_t^D}{A_t}\right) + \Delta \log(A_t) = 100 * (\hat{i}_t - \hat{i}_{t-1} + \hat{z}_t) + 100\gamma$$

$$\log L_t^D = 100 * \hat{L}_t + 100 \log(L_{ss})$$

$$\Delta \log(\frac{W}{P})_t^D = 100 * (\hat{w}_t - \hat{w}_{t-1} + \hat{z}_t) + 100\gamma$$

$$\pi_t^D = 100 * \hat{\pi}_t + \pi_{ss}^o$$

$$R_t^D/4 = 100 * \hat{R}_t + R_{ss}^o$$

$$\log\left(\frac{B_t}{Y_t}\right)_t^D = 100 * (\hat{d}_t - \hat{y}_t) + 100 \log(d_{ss}) + \varepsilon_t^{me}$$

where variables with a hat denote deviations from the steady state and ε_t^{me} represents a measurement error. The measurement error is included because the debt-to-GDP ratio is detrended using a band-pass filter that removes fluctuations with periodicities longer than 15 years.

E.3 Prior and posterior estimates

Table E.1: Priors densities and posterior estimates for the baseline model

		Prior			Posterior		
Coefficient	**Description**	**Density**[1]	**Mean**	**Std**	**Median**	**Std**	**[5 , 95]**[2]
α	Capital share	N	0.30	0.05	0.16	0.02	[0.13, 0.19]
ι_p	Price indexation	B	0.50	0.15	0.32	0.10	[0.16, 0.48]
ι_w	Wage indexation	B	0.50	0.15	0.36	0.09	[0.22, 0.50]
γ	SS technology growth rate	N	0.50	0.03	0.49	0.03	[0.45, 0.53]
h	Consumption habit	B	0.50	0.10	0.57	0.06	[0.48, 0.67]
λ_p^{ss}	SS price markup	N	0.15	0.05	0.19	0.04	[0.12, 0.25]
λ_w^{ss}	SS wage markup	N	0.15	0.05	0.13	0.05	[0.04, 0.21]
$\log(L^{ss})$	SS log-hours	N	0.00	0.50	0.51	0.40	[-0.15, 1.15]
$100(\pi^{ss} - 1)$	SS quarterly inflation	N	0.50	0.10	0.57	0.07	[0.45, 0.69]
$100(\beta^{-1} - 1)$	Discount factor	G	0.25	0.20	0.14	0.10	[0.00, 0.28]

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		Prior			Posterior		
Coefficient	**Description**	**Density**[1]	**Mean**	**Std**	**Median**	**Std**	**[5 , 95]**[2]
ν	Inverse Frisch elasticity	G	2.00	0.75	3.77	0.95	[2.22, 5.30]
ξ_p	Calvo price	B	0.66	0.10	0.96	0.01	[0.95, 0.98]
ξ_w	Calvo wage	B	0.66	0.10	0.76	0.06	[0.66, 0.86]
χ	Elasticity of capital utilization costs	G	5.00	1.00	5.43	1.01	[3.74, 7.00]
S''	Investment adjustment costs	G	4.00	1.00	3.20	0.75	[1.96, 4.36]
ϕ_π	Taylor rule inflation	N	1.70	0.30	1.52	0.26	[1.09, 1.94]
ϕ_x	Taylor rule output	N	0.13	0.05	0.04	0.04	[-0.03, 0.10]
$\phi_{\Delta x}$	Taylor rule output growth	N	0.13	0.05	0.18	0.04	[0.12, 0.24]
ϕ_r	Taylor rule smoothing	B	0.60	0.10	0.83	0.04	[0.76, 0.89]
ϕ_{R^*}	Taylor rule natural rate	N	1.00	0.15	0.80	0.17	[0.52, 1.06]
ϕ_{tax}	Tax rule smoothing	B	0.60	0.20	0.05	0.02	[0.02, 0.09]
ρ_η	Liquidity	B	0.60	0.20	0.96	0.02	[0.93, 0.99]
ρ_{mps}	Monetary policy	B	0.40	0.20	0.12	0.06	[0.02, 0.20]
ρ_z	Neutral technology growth	B	0.60	0.20	0.08	0.04	[0.02, 0.14]
ρ_μ	Investment	B	0.60	0.20	0.24	0.15	[0.03, 0.44]
ρ_p	Price-markup	B	0.60	0.20	0.84	0.05	[0.76, 0.92]
ρ_w	Wage-markup	B	0.60	0.20	0.81	0.15	[0.58, 0.98]
θ_p	Price markup MA	B	0.50	0.20	0.78	0.07	[0.68, 0.88]
θ_w	Wage markup MA	B	0.50	0.20	0.80	0.15	[0.56, 0.97]
ρ_b	Intertemporal preference	B	0.60	0.20	0.78	0.12	[0.67, 0.90]
ρ_g	Government spending	B	0.60	0.20	0.97	0.01	[0.96, 0.99]
ρ_{tax}	Tax	B	0.40	0.20	0.93	0.02	[0.90, 0.97]
ϕ_B	Elasticity of bonds' utility	G	0.25	0.05	0.11	0.03	[0.07, 0.16]

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		Prior			Posterior		
Coefficient	Description	Density[1]	Mean	Std	Median	Std	[5 , 95][2]
τ_d	Tax rule debt	N	0.15	0.10	0.27	0.04	[0.19, 0.34]
τ_R	Tax rule spending	G	1.00	0.40	1.25	0.25	[0.84, 1.64]
τ_y	Tax rule output	G	0.33	0.10	0.29	0.07	[0.17, 0.41]
τ_{yy}	Tax rule lagged output	G	0.33	0.10	0.13	0.04	[0.07, 0.18]
d_y	SS debt-to-GDP	N	0.65	0.50	0.65	0.01	[0.63, 0.67]
$100\sigma_{mps}$	Monetary policy	I	0.10	1.00	0.20	0.01	[0.17, 0.22]
$100\sigma_{\eta}$	Liquidity	I	0.50	1.00	0.42	0.08	[0.30, 0.54]
$100\sigma_z$	Neutral technology growth	I	0.50	1.00	0.68	0.04	[0.60, 0.75]
$100\sigma_b$	Intertemporal preference	I	0.10	1.00	0.03	0.01	[0.02, 0.05]
$100\sigma_g$	Government spending	I	0.50	1.00	0.55	0.03	[0.50, 0.60]
$100\sigma_{\mu}$	Investment	I	0.50	1.00	4.82	1.29	[2.77, 6.86]
$100\sigma_{tax}$	Tax	I	0.50	1.00	0.72	0.10	[0.56, 0.88]
$100\sigma_{\lambda_p}$	Price-markup	I	0.10	1.00	0.11	0.01	[0.09, 0.13]
$100\sigma_{\lambda_w}$	Wage-markup	I	0.10	1.00	0.39	0.03	[0.34, 0.44]
$100\sigma_{me}^{debt}$	Measurement error debt	I	1.00	1.00	1.15	0.11	[0.96, 1.33]

[1] Prior distribution type: N = Normal, B = Beta, G = Gamma, I = Inverted-Gamma1.

[2] Posterior medians and percentiles are computed from three Metropolis–Hastings chains of 120,000 draws each, discarding the first 25,000 as burn-in.

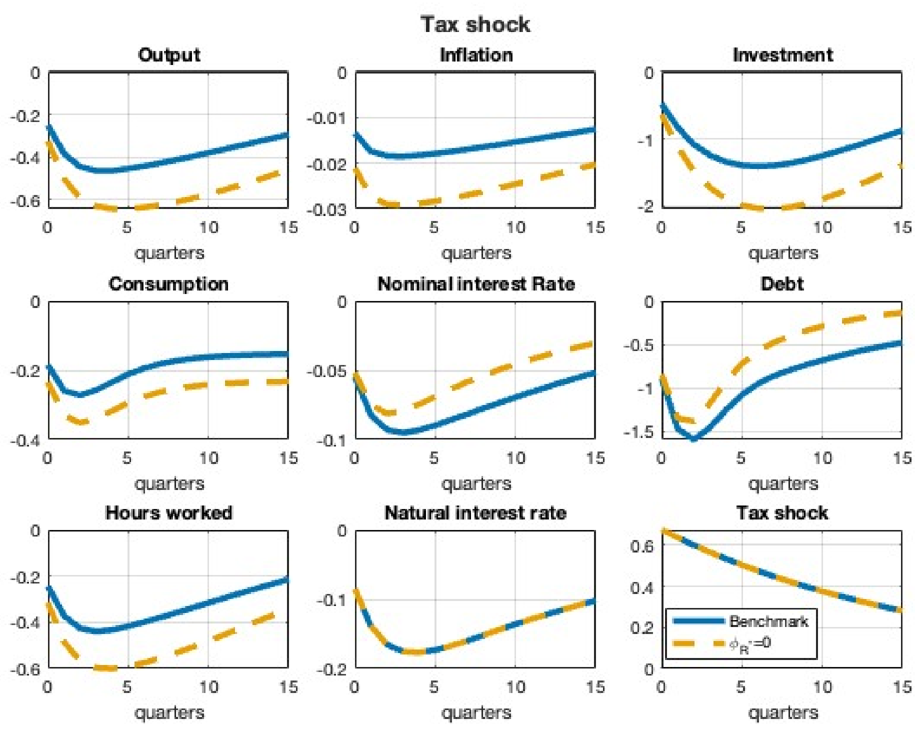
E.4 Model additional results

Table E.2: Posterior variance decomposition at the business cycle frequency

	Preference	Liquidity	Govt spending	Price markup	Wage markup	Monetary policy	Investment	Tax	Technology
GDP	0.07	0.36	0.03	0.02	0.00	0.06	0.05	0.18	0.23
Consumption	0.27	0.16	0.20	0.00	0.01	0.04	0.01	0.08	0.23
Investment	0.08	0.35	0.06	0.03	0.01	0.04	0.21	0.17	0.05
Hours worked	0.08	0.47	0.04	0.02	0.00	0.08	0.05	0.23	0.04
Wage	0.00	0.08	0.01	0.06	0.73	0.00	0.00	0.04	0.08
Inflation	0.00	0.15	0.02	0.77	0.04	0.00	0.00	0.02	0.00
Debt	0.07	0.41	0.08	0.03	0.00	0.09	0.05	0.21	0.05
Interest rate	0.02	0.54	0.03	0.06	0.00	0.23	0.00	0.12	0.00
Natural rate	0.13	0.38	0.13	0.00	0.00	0.00	0.10	0.10	0.17

Notes: Business-cycle frequencies correspond to cyclical components with periods between 6 and 32 quarters. The variance decomposition is obtained from the spectral representation of the DSGE model. An inverse first-difference filter is applied to GDP, consumption, and investment to recover their level components. The spectral density is computed from the model's state-space representation using 500 frequency bins covering the range of business-cycle periodicities. The figure shows that liquidity (safety) shocks account for an important share of business-cycle fluctuations.

Figure E.1: Impulse response function to a tax shock



Notes: The figure shows the impulse response functions to a one-standard-deviation tax shock in the estimated DSGE model. The blue line corresponds to the estimated Taylor rule, while the yellow line corresponds to the rule with no response to the natural rate, $\phi_{R^*} = 0$. The panels display, in order, output, inflation, investment, consumption, the nominal interest rate, public debt, hours worked, marginal cost, and the natural rate of interest.