Government debt maturity and monetary policy*

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Abstract

We study how the maturity structure of consolidated government debt shapes monetary transmission and welfare. Empirically, we show that a US monetary tightening persistently lowers government purchases and raises debt, while transfers do not respond and tax receipts fall with activity. In a New Keynesian model with separate fiscal and central bank balance sheets, monetary tightening is amplified through a fiscal channel: rising interest costs on debt force spending cuts. The strength of this channel depends on the short-term debt share and on how central bank losses pass to the Treasury. From a welfare perspective, the optimal maturity structure depends on the policy regime. Under a Taylor rule, short-term debt dampens the response of public spending to demand shocks and welfare peaks at an interior share of short-term debt. Under optimal policy with commitment, long-term debt is best because it allows the central bank to stabilise demand fluctuations without contemporaneous fiscal disruptions.

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1 Introduction

Changes in interest rates have immediate effects on government budgets through an increase in interest costs on debt. In response to higher interest costs, governments must either change spending, taxation or debt issuance. In turn, fiscal adjustments can trigger a macroeconomic response, depending on the particular margin for adjustment. Changes in government purchases, in particular, directly affect output through public demand. The fiscal response to changes in monetary policy also depends on the maturity profile of government debt. Governments typically issue fixed rate liabilities, so changes in interest rates only matter for government budgets once governments roll over maturing debt. As a result, when the government has a large share of short-term liabilities, the fiscal channel of monetary policy is particularly salient. Quantitative easing programs have significantly shortened the maturity profile of consolidated government debt across many advanced economies, increasing the interest rate sensitivity of government budgets.

In this paper, we study how the maturity structure of consolidated government debt shapes monetary transmission and optimal policy. Empirically, we find that the US government cuts spending and raise debt issuance in response to monetary shocks. In a New Keynesian model, fiscal adjustments amplify the effect of a monetary tightening, and the amplification is larger when more of the government's consolidated debt is short-term. Under a Taylor rule, short-term debt dampens the response of public spending to demand shocks, but with a high short-term share spending cuts in response to rate hikes can excessively weigh on output, so the optimal short-term share is interior. Under optimal policy with commitment, however, welfare is highest when debt is long-term because the central bank is free to adjust rates without large contemporaneous spillovers to fiscal policy.

We build a New Keynesian model with separate fiscal and monetary authority balance sheets. The fiscal authority issues short- and long-term nominal bonds and follows a fiscal rule disciplined by our empirical estimates. The central bank holds long-term bonds financed with interest-bearing reserves, follows a zero-net-worth rule, and remits its income to the Treasury. When interest on reserves rises, remittances fall and the fiscal authority cuts purchases, reducing aggregate demand. The strength of this fiscal channel depends on the share of the government's consolidated debt that is short-term, so central bank asset purchases raise fiscal amplification of monetary policy. The remittance rule matters for how this plays out: when the central bank instead finances its losses by issuing reserves, as under the Federal Reserve's deferred asset arrangement, the short-run fall in purchases is close to the case without asset purchases, but consolidated debt stays persistently higher.

To calibrate the model, we document how US fiscal variables respond to monetary policy

shocks. We identify shocks using high-frequency surprises in federal funds futures around FOMC announcements, using the sign restrictions of Jarociński and Karadi (2020) to purge central bank information effects. In an internal-instruments VAR on monthly data from 1990 to 2016, a monetary tightening that raises the one-year yield by 25 basis points lowers government purchases by around half a per cent and raises the par value of government debt by around 0.4 per cent in the first quarter. Over the following three years purchases keep falling, to around two per cent below baseline, while debt stays around one per cent higher. Tax receipts fall with activity, while social transfers do not respond.

Finally, we study the optimal maturity structure of government debt in our model. We derive a second-order approximation to household welfare around an efficient steady state in which households value both private and public consumption. Under a Taylor rule, a positive demand shock relaxes the government budget through higher tax revenues and inflation, so public spending rises procyclically. Short-term debt makes the budget sensitive to the policy rate, so a tightening also restrains public spending, but with a high short-term share the spending cuts cause output to overshoot below steady state. Welfare peaks at around 50 per cent short-term debt under our baseline fiscal rule. Under optimal policy with commitment, long-term debt lets the central bank raise rates sharply on impact without disrupting the budget, while with short-term debt a rate rise directly tightens the budget, so the central bank chooses a small but persistent tightening. Under our baseline fiscal rule, welfare losses rise with the share of short-term debt. Finally, we show that to a first order, new asset purchases do not change remittances, but the central bank's inherited balance sheet shifts the effective maturity of consolidated debt, and so determines where the economy sits on these welfare curves.

Understanding the transmission of monetary policy is important for successful conduct of monetary policy. The fiscal channel of monetary policy suggests a significant time variation in the transmission of monetary policy. For example, changes in the maturity structure of government debt over time, through unconventional monetary policies or changing issuance patterns, will imply time variation in the size of the economic response size to interest rate changes. Further, the importance of fiscal rules, which are influenced by institutional and political forces, implies further time variation and can present significant uncertainty for policymakers.

Related literature Kaplan et al. (2018) highlight the fiscal channel of monetary policy as a key distinction between heterogeneous agent New Keynesian (HANK) and representative agent New Keynesian (RANK) models. In the same framework, Alves et al. (2020) further explore the dependence of the channel on fiscal rules. Similarly, in a HANK model, Auclert

et al. (2020) show that when the fiscal authority primarily issues debt in response to interest rate changes, the margin for adjustment in the government's budget constraint is no longer quantitatively important. Further, they show that if the government only issues long-term bonds then the channel is also significantly muted. In this paper, we show that the share of short-term debt is the relevant metric for determining the size of the fiscal response, rather than the average duration of debt, meaning that models should include both short and long-term bonds in order to correctly capture the fiscal channel. Further, we identify empirical fiscal adjustment rules to monetary policy shocks in the US.

This paper is connected to the literature on monetary-fiscal interactions and estimates of fiscal rules. Sargent and Wallace (1981) show that fiscal policy can constrain the ability of central banks to control inflation. Leeper (1991) analyses monetary-fiscal interactions through monetary rules, where the central bank responds to inflation, and fiscal rules, where the fiscal authority responds to government debt; we take a similar approach in our model. A number of papers estimate empirical fiscal rules (Davig and Leeper, 2011, Fernández-Villaverde et al., 2015, Bianchi and Melosi, 2017). We contribute to this literature by providing causal estimates of the fiscal response to monetary policy shocks. Our empirical framework is similar to Bouscasse and Hong (2023), who also use a structural VAR to estimate the response of fiscal variables to monetary policy shocks. However, Bouscasse and Hong (2023) use Romer and Romer (2004) monetary shocks, and, likely as a result of their choice of instrument, their estimates show the price puzzle. We build on these estimates by using high-frequency identification of monetary shocks, following Jarociński and Karadi (2020) and Gertler and Karadi (2015). Relatedly, using sign restrictions to identify monetary shocks, Reichlin et al. (2023) estimate the response of government debt and deficits to monetary shocks in the euro area, but do not directly measure changes in government spending.

Our welfare analysis relates to work on optimal monetary policy in the New Keynesian model (Clarida et al., 1999, Woodford, 2003, Galí and Monacelli, 2008). We add a fiscal authority whose spending responds to interest costs, which makes the maturity structure of government debt a determinant of both the welfare-relevant trade-offs and the optimal path of the policy rate.

More broadly, this paper relates to the literature on fiscal stimulus through government purchases. Ramey (2019) provides a review of the empirical and theoretical literature on fiscal multipliers. Woodford (2011) presents analytical derivations of fiscal multipliers in the New Keynesian model under a range of assumptions. In our model, government purchases crowd out of private consumption, as is standard in New Keynesian models. This literature has emphasised that fiscal multipliers, theoretically and in the data, appear to be time

varying. For example, there is evidence that multipliers are larger at the zero lower bound (Ramey, 2019). In our model, time varying fiscal multipliers would also imply time variation in the real effects of monetary policy.

Finally, this paper relates to the literature on the fiscal implications of expanded central bank balance sheets. R. Hall and Reis (2015) consider risks to central solvency following large asset purchase programs. They show that if central banks remit net income to the fiscal authority they will always be solvent, provided that remittances can be negative. Del Negro and Sims (2015) study how fiscal support can be necessary for a central bank to control inflation. Benigno (2020) shows how central banks can control the price level through an appropriately specified remittance policy. These papers separate the central bank and fiscal balance sheets. We contribute to this literature by showing that one implication of large duration risk on the central bank's balance sheet is the amplification of conventional monetary policy, since central bank losses affect the fiscal authority's intertemporal budget constraint, that the size and timing of this amplification depend on the remittance rule, and that the resulting shortening of consolidated debt maturity changes the welfare consequences of monetary policy.

Outline The paper is structured as follows. Section 2 presents the model. Section 3 presents the empirical evidence on the fiscal response to monetary policy shocks and the calibration. Section 4 studies monetary policy transmission, including the roles of asset purchases, remittance rules and the fiscal rule. Section 5 studies the welfare implications of the maturity structure under a Taylor rule and under optimal policy, and the role of central bank balance sheets. Section 6 concludes.

2 Model

2.1 Households

There is a measure one of identical households. Time is discrete. Households receive utility from consumption, C_t, and government consumption, G_t, and disutility from hours worked, H_t,

$$U_t(C_t, G_t, H_t; \epsilon_t^d) = \left\{ (1-\chi)\frac{C_t^{1-\gamma}}{1-\gamma} + \chi\frac{G_t^{1-\gamma}}{1-\gamma} - \nu\frac{H_t^{1+\eta}}{1+\eta} \right\} e^{\epsilon_t^d},$$

where ϵ_t^d is a preference shock that follows an AR(1) process with persistence ρ.

Households earn a real wage $\frac{W_t}{P_t}$ where W_t is the nominal wage and P_t is the price level. Inflation is defined as $\pi_t = \frac{P_t}{P_{t-1}} - 1$. Households pay proportional labour income taxes at

a rate τ and receive lump sum transfers T_t. At each period t, households invest in nominal short-term bonds, nominal central bank reserves and Woodford (2001)-style nominal long-term bonds. The short-term bond and reserves have a gross nominal return of $1 + i_t$. The long-term bond pays a geometrically decaying stream of coupons: a bond issued at t pays $1, \delta, \delta^2, \ldots$ from $t+1$ onwards, and has price Q_t. Let A_t^h, M_t^h and B_t^h denote the household's holdings of short-term bonds (face value), reserves and long-term coupons, all in real terms. The household budget constraint is

$$C_t + \frac{A_t^h}{1+i_t} + M_t^h + Q_t B_t^h = (1-\tau)\frac{W_t}{P_t}H_t + T_t + \frac{A_{t-1}^h + (1+i_{t-1})M_{t-1}^h + (1+\delta Q_t)B_{t-1}^h}{1+\pi_t}.$$

2.2 Firms

There is a representative firm producing output, Y_t, with a linear production function. The firm has productivity, z_t, and uses labour, H_t as the input into production,

$$Y_t = z_t H_t.$$

The labour input H_t is an aggregate of differentiated types of labour indexed by $j \in [0,1]$

$$H_t = \left(\int_0^1 H_{tj}^{1-\frac{1}{\varepsilon}} dj \right)^{\frac{\varepsilon}{\varepsilon-1}}.$$

Cost minimisation for the firm implies that demand for labour type j will be

$$H_{tj} = \left(\frac{W_{tj}}{W_t} \right)^{-\varepsilon} H_t, \tag{1}$$

where W_t is the aggregate wage index

$$W_t = \left(\int_0^1 W_{tj}^{1-\varepsilon} dj \right)^{\frac{1}{1-\varepsilon}}.$$

The price of the consumption good, P_t, is flexible.

2.3 Unions

Wages are sticky, closely following the textbook micro-foundation in Galí (2015). Each household is composed of a continuum of members each specialising in a type of labour j. Workers specialised in each type of labour are represented by unions. Unions set the wage for each type of labour, but can only change their nominal wage with probability $1-\theta$ each

period. A union resetting its wage at t chooses W_t^* to maximise household utility subject to labour demand (1). The first order condition is

$$\sum_{k=0}^{\infty}(\beta\theta)^k \,\mathbb{E}_t \, H_{t+k|t} \left((1-\chi) C_{t+k}^{-\gamma} (1-\tau) \frac{W_t^*}{P_{t+k}} - \frac{\varepsilon}{\varepsilon - 1} \nu H_{t+k|t}^{\eta} \right) = 0,$$

where $H_{t+k|t}$ is the labour demanded at $t+k$ from a union that last reset its wage at t. Log-linearising around the steady state, we get the wage Phillips curve

$$\theta \pi_{wt} = (1-\beta\theta)(1-\theta) \left(\mu \frac{\nu H_t^{\eta} C_t^{\gamma}}{(1-\chi)\frac{W_t}{P_t}(1-\tau)} - 1 \right) + \beta\theta \, \mathbb{E}_t \, \pi_{wt+1},$$

where $\mu = \frac{\varepsilon}{\varepsilon - 1}$ is the union mark-up and $\pi_{wt} = \frac{W_t}{W_{t-1}} - 1$ is wage inflation.

2.4 Government

There is a government composed of a fiscal authority and a monetary authority with separate balance sheets. The distinction between the two balance sheets is somewhat artificial in that all central bank losses are ultimately borne by the fiscal authority. However, the key mechanism in our model depends on the rule followed by the fiscal authority. The empirical counterpart of this rule is likely to be influenced by political and institutional features, for example different political treatment of on-balance sheet and off-balance sheet costs. Our deconsolidated modelling approach attempts to capture some of these institutional features.

Fiscal authority The fiscal authority issues short and long-term nominal bonds A_t and Z_t held by the household, at price $\frac{1}{1+i_t}$ and Q_t, respectively. Then, in each period it has to repay the short-term debt and the coupons of long-term debt B_{t-1}. All variables, including the nominal assets, are expressed in real terms. The long-term coupons B_t follow a slow-moving autoregressive process, with autoregressive coefficient δ[1]. It makes lump sum transfers T_t to the household and raises proportional labour income taxes at a rate τ. Following the empirical findings in Section 3.1, we assume that both transfers and the tax rate are constant ($T_t = T$ and $\tau_t = \tau$). It receives possibly negative remittances from the monetary authority R_t. The budget constraint of the government and the law of motion for nominal coupons of

[1]Define as B_t^n the nominal coupons (in nominal terms) that the government has to repay at time $t+1$, while Z_t^n are the nominal bonds (in nominal terms) issued at time t. B_t^n is equal to the coupons of the bonds issued today (Z_t^n), of the non-decayed bonds issued in $t-1$ (δZ_{t-1}^n), those issued in $t-2$ ($\delta^2 Z_{t-2}^n$), and so on. Therefore, one can write the nominal coupons to be repaid at time $t+1$ as: $B_t^n = \sum_{j=0}^{\infty} \delta^j Z_{t-j}^n = \delta B_{t-1}^n + Z_t^n$. Finally, dividing by the price level P_t, one gets equation (3).

long-term debt are:

$$\frac{B_{t-1}}{1+\pi_t} + \frac{A_{t-1}}{1+\pi_t} + T + G_t = \frac{A_t}{1+i_t} + Q_t Z_t + \tau Y_t + R_t \tag{2}$$

$$B_t = \delta \frac{B_{t-1}}{1+\pi_t} + Z_t \tag{3}$$

We define a fiscal rule based on the book-value of debt, rather than the market value, since the US debt ceiling is based on the par value of outstanding federal debt (G. J. Hall & Sargent, 2018). Therefore, we define the book-value of long-term government debt $\tilde{B}_t$ as[2]:

$$\tilde{B}_t = \delta \frac{\tilde{B}_{t-1}}{1+\pi_t} + Q_t Z_t \tag{4}$$

and the book-value of aggregate debt D_t simply as the sum of short-term debt and the book-value of long-term debt:

$$D_t = \frac{A_t}{1+i_t} + \tilde{B}_t \tag{5}$$

Similar to Auclert et al. (2020), we assume that the fiscal authority adjusts debt and purchases according to:

$$\bar{G} - G_t = \psi(D_t - \bar{D}), \tag{6}$$

where $\psi > 0$ and bars denote steady-state values. In response to changes in the real interest rate and tax revenue, debt and government spending adjust so that the budget constraint (2) holds, and the rule (6) pins down the split between the two. Higher values of ψ imply a larger initial adjustment in spending compared to debt in response to shocks. ψ must also be large enough to ensure a bounded solution for the path of government debt. This is a convenient specification for the fiscal rule because it characterises the evolution of both debt and spending through a single parameter, which we calibrate in Section 3 using the empirical impulse responses.

Finally, we assume that the fiscal authority issues a constant share of its debt in the short-term bond

$$\frac{A_t}{1+i_t} = \zeta D_t. \tag{7}$$

[2]Define as $\tilde{B}_t^n$ the book-value (in nominal terms) of long-term government debt at time t, while $Q_t Z_t^n$ are the nominal bonds (in nominal terms) issued at time t. $\tilde{B}_t^n$ is equal to the sum of the nominal bonds issued today ($Q_t Z_t^n$), of the non-decayed bonds issued in $t-1$ ($\delta Q_{t-1} Z_{t-1}^n$), those issued in $t-2$ ($\delta^2 Q_{t-2} Z_{t-2}^n$), and so on. Therefore, one can write the book-value (in nominal terms) of long-term government debt as: $\tilde{B}_t^n = \sum_{j=0}^{\infty} \delta^j Q_{t-j} Z_{t-j}^n = \delta \tilde{B}_{t-1}^n + Q_t Z_t^n$. Finally, dividing by the price level P_t, one gets equation (4).

Monetary authority The monetary authority issues interest-bearing reserves, M_t, which have the same interest rate as the short-term bond and holds long-term bonds B_t^c. In each period it purchases new long-term government bonds Z_t^c and receives the coupons on the bonds it holds. It transfers or receives fiscal backing by the government through remittances R_t. The monetary authority budget constraint and the law of motion for coupons earned on long-term debt are:

$$R_t + \frac{1 + i_{t-1}}{1 + \pi_t} M_{t-1} + Q_t Z_t^c = M_t + \frac{B_{t-1}^c}{1 + \pi_t} \tag{8}$$

$$B_t^c = \delta \frac{B_{t-1}^c}{1 + \pi_t} + Z_t^c \tag{9}$$

Similarly to the case of government debt, we define the book-value of the asset side of the central bank as:

$$\tilde{B}_t^c = \delta \frac{\tilde{B}_{t-1}^c}{1 + \pi_t} + Q_t Z_t^c \tag{10}$$

We assume that the central bank follows a "constant zero net worth" rule, in which the asset side is computed at book value:

$$M_t = \tilde{B}_t^c \tag{11}$$

Remittance policies vary across central banks, though many operate with negative capital following losses, rather than seeking an immediate recapitalisation. For example, when the Fed has earnings losses it does not remit profits to the Treasury and instead accumulates a "deferred asset" equal to its cumulative losses (Anderson et al., 2022). Once earnings are positive again, the Fed does not remit any profits until the deferred asset has been paid down in full. The deferred asset is booked as a negative liability since it reflects a reduction in future liabilities to the Treasury. From an accounting standpoint, this means that operating losses do not affect the Fed's capital position. In economic terms, the Fed finances its losses by issuing reserves and repays them gradually out of future income. Since we solve the model with perturbation methods, we do not impose a non-negativity constraint on remittances. Instead, in Section 4 we capture delayed pass-through with an alternative remittance rule, under which the central bank holds a constant stock of long-term bonds and adjusts remittances gradually in response to its reserves,

$$R_t - \bar{R} = -\vartheta \left(M_t - \bar{M} \right). \tag{12}$$

Under this rule, a fall in central bank income is initially financed by issuing reserves and passed to the fiscal authority only slowly, with $\vartheta > 0$ governing the speed of pass-through.

The monetary authority sets the nominal interest rate on both short-term debt and

reserves according to a Taylor rule

$$1 + i_t = (1 + \bar{i}) (1 + \pi_t)^{\phi_\pi} \left(\frac{Y_t}{\bar{Y}} \right)^{\phi_y} \exp (\varepsilon_t^m) \tag{13}$$

where $\bar{i}$ is the steady state nominal interest rate, ϕ_π and ϕ_y are Taylor rule coefficients governing the responsiveness of the monetary authority to inflation and output, and ε_t^m is a monetary policy shock. In Section 5 we also study optimal policy under commitment, which replaces the Taylor rule.

2.5 Equilibrium

Given sequences of shocks, $\{\varepsilon_t^m, \epsilon_t^d, z_t\}_{t \geq 0}$, an equilibrium is a sequence of household choices,

$$\{C_t, H_t, A_t^h, M_t^h, B_t^h\},$$

prices, $\{W_t, P_t, i_t, Q_t\}$, and government policies,

$$\{A_t, B_t, Z_t, G_t, D_t, M_t, B_t^c, Z_t^c, R_t\},$$

such that households optimise, unions optimise, firms optimise, the fiscal and monetary authorities follow their rules and budget constraints, asset markets clear,

$$\begin{aligned} A_t^h &= A_t, \\ M_t^h &= M_t, \\ B_t^h &= B_t - B_t^c, \end{aligned}$$

and the goods market clears,

$$C_t + G_t = Y_t = z_t H_t.$$

3 Empirical evidence and calibration

3.1 Monetary-fiscal interactions in the data

In this section, we estimate the effect of monetary policy shocks on a number of fiscal variables. Following Gertler and Karadi (2015), we identify monetary policy shocks using high-frequency interest rate surprises, measured through changes in the three-month federal funds rate futures in a 30-minute window around Federal Open Market Committee

announcements. A potential challenge for identification in this framework is that changes in the federal funds rate could also reflect an "information" shock if the Federal Reserve reveals previously private information. In particular, information shocks could prompt an adjustment to the stance of fiscal policy. For example, bad news about the state of the economy could prompt fiscal policymakers to use fiscal stimulus. To address this concern, we use the poor man's sign restriction approach proposed by Jarociński and Karadi (2020) in order to abstract from any information effects. The Jarociński and Karadi (2020) approach separates federal funds futures surprises into observations where the federal funds rate moves in the opposite direction as the S&P 500, corresponding to a pure monetary shock, and those where the futures and S&P 500 move in the same direction, corresponding to an information shock.

We compute structural impulse response functions using an internal instruments recursive VAR. Let s_t denote the monetary shock instrument, w_t denote the vector of outcome variables and $x_t = [s_t, w_t]$. We estimate

$$x_t = \sum_{j=1}^{p} \Gamma_j x_{t-j} + \Theta u_t,$$

where $\{\Gamma_j\}_{j=1}^{p}$ are the reduced form coefficient matrices and u_t is the vector of structural innovations. The first column of Θ is identified by ordering the monetary policy shock instrument first in the VAR through a Cholesky decomposition of the covariance matrix of the reduced form residuals, $\Sigma = \Theta\Theta'$. We then compute the structural IRFs for the monetary policy shock by multiplying the reduced form impulse responses by the first column of Θ.

Following Gertler and Karadi (2015) and Jarociński and Karadi (2020) our outcome variables w_t include the one-year bond yield, a measure of the price level (in our case the GDP deflator), output (in our case industrial production) and the excess bond premium (measuring financial conditions; Gilchrist and Zakrajšek, 2012). We then add four additional fiscal variables: government debt, purchases, tax receipts and transfers. All non-financial variables are measured in log levels. We estimate the VAR with 12 lags and compute standard errors using a wild bootstrap.

3.1.1 Data

Our sample is from 1990 to 2016 at a monthly frequency. We use the data set constructed by Jarociński and Karadi (2020) for our data on federal funds rate surprises, industrial production, the GDP deflator and the excess bond premium. This dataset also contains monthly estimates of government purchases, which underlie their monthly GDP series. This series is interpolated from quarterly data, following the methodology proposed by Stock and Watson (2010). The Stock and Watson (2010) methodology estimates the monthly values

underlying quarterly government purchases using the Kalman smoother, with government wages, public construction and defence manufacturing sales used as predictors for the latent monthly values of government purchases.

We supplement these data with the par value of government debt, federal tax receipts and social benefit payments. The par value of government debt is reported by the Treasury in the Monthly Statement of Public Debt.[3] We use total federal tax receipts as reported by the Treasury in the Monthly Treasury Statement.[4] We seasonally adjust the raw tax receipts data. We measure government transfers with "personal current transfer receipts: government social benefits to persons" from the US Bureau of Economic Analysis monthly Personal Income and Outlays release.[5]

3.1.2 Estimated impulse response functions

Figures 1 and 2 show the estimated impulse responses to a monetary shock. The IRFs are normalised so that the monetary policy shock raises the one-year yield by 25 basis points on impact. The one-year yield rises further over the first half year and returns to zero after around a year and a half. The non-fiscal variables show patterns consistent with standard theory. The price level declines persistently over the impulse response horizon. Industrial production falls, reaching a trough after a little over a year following the monetary shock. Financial conditions tighten, with the excess bond premium peaking at around 0.6 percentage points higher after seven months.

On the fiscal side, a positive monetary policy shock leads to a persistent reduction in government purchases, while government debt rises. In the first quarter following the shock, government purchases fall by around half a per cent and government debt rises by around 0.4 per cent. Over the following three years, purchases continue to decline, to around two per cent below baseline, while debt stabilises at around one per cent above baseline. Tax receipts fall and remain persistently lower, consistent with the drop in activity but inconsistent with a compensating adjustment in tax rates. Government transfers do not show clear signs of change, with the impulse response hovering around zero throughout the horizon.

[3]We take these data from the Dallas Federal Reserve, who also provide a monthly series of the market value of government debt. We prefer to use the par value since monetary shocks should also lead to a revaluation of government debt, whereas we are interested in net issuance in response to monetary shocks. Using the par value is consistent with our model in Section 2, where the fiscal rule is defined on the book value of debt, which, like the par value, is not revalued when bond prices change.

[4]We retrieve the tax receipts data from FRED [MTSR133FMS].

[5]We retrieve the social benefits data from FRED [A063RC1].

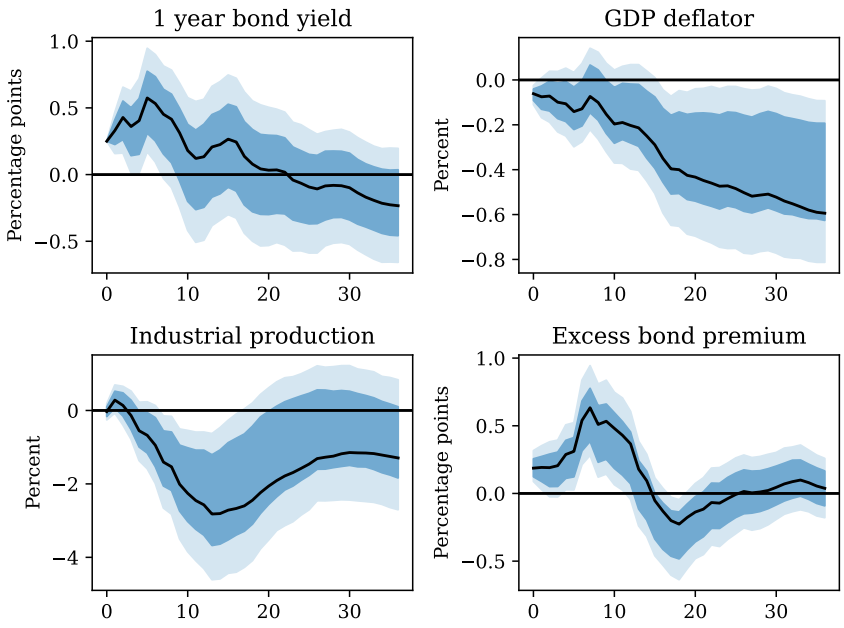


Figure 1: Impulse responses to a monetary policy shock – non-fiscal variables

Notes: Shocks are normalised to correspond to a 25 basis point increase in the one-year bond yield. The impulse response functions are estimated using the internal instrument VAR described in section 3.1, using Jarociński and Karadi (2020)'s poor man sign restrictions on federal funds rate surprises in a 30-minute window around FOMC announcements. The VAR includes the one-year bond yield, the GDP deflator, industrial production, the excess bond premium (Gilchrist and Zakrajšek, 2012), government debt, tax receipts, government purchases and government social benefits, estimated with 12 lags. The shaded areas are 68 and 90 per cent confidence intervals, computed using a wild bootstrap.

3.2 Remaining parameters

We calibrate at a quarterly frequency. We choose the discount factor β to match the average nominal annualised 3-month Treasury bill yield of 2.8 per cent over the time period in section 3.1. We set ν so that steady state output and labour supply are one. We set $T = 0.05$ to match social security payments as a share of GDP and $\tau = 0.2$ to match federal receipts as a share of GDP (CBO, 2023). We set debt to 100 per cent of annualised output, with 30 per cent of the steady state value in the short-term bond (CBO, 2023, US Treasury, 2023). We choose δ so that the long-term bonds have an average duration of 7.4 years, implying an average duration of government debt of 5 years, consistent with the average duration of unconsolidated government debt in the data (Mitra and Sack, 2022). Given T, τ and $\bar{D}$, steady state government purchases are determined residually.[6] We set ψ to match the average relative changes over the first quarter in Figure 2: in the first quarter,

[6]The steady state value, $\bar{G}$, is 0.12. In the data we use in Section 3.1, the average ratio of government spending to output is 0.18, though towards the end of the sample, the value is around 0.14.

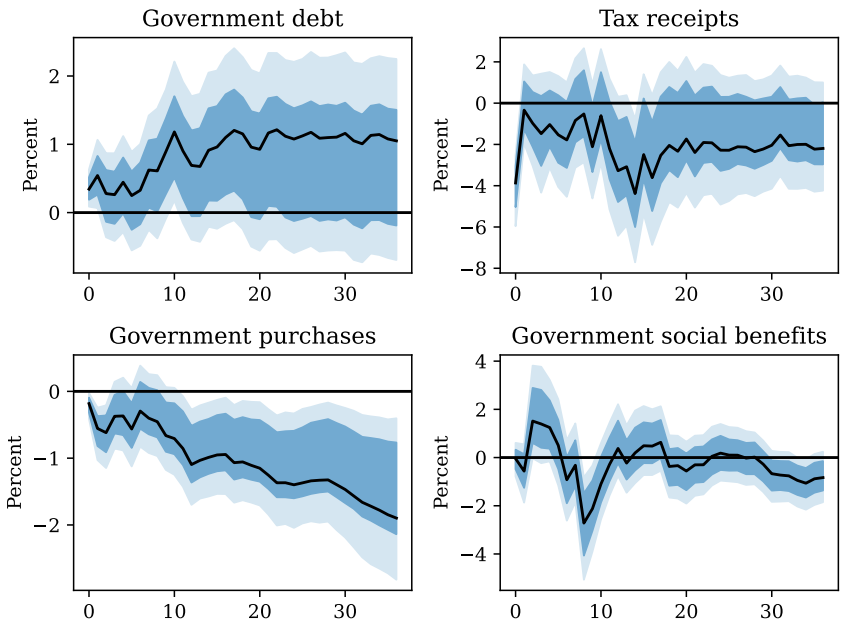


Figure 2: Impulse responses to a monetary policy shock – fiscal variables

Notes: Shocks are normalised to correspond to a 25 basis point increase in the one-year bond yield. The impulse response functions are estimated using the internal instrument VAR described in section 3.1, using Jarociński and Karadi (2020)'s poor man sign restrictions on federal funds rate surprises in a 30-minute window around FOMC announcements. The VAR includes the one-year bond yield, the GDP deflator, industrial production, the excess bond premium (Gilchrist and Zakrajšek, 2012), government debt, tax receipts, government purchases and government social benefits, estimated with 12 lags. The shaded areas are 68 and 90 per cent confidence intervals, computed using a wild bootstrap.

the ratio of the per cent change in annualised government purchases to the per cent change in government debt is -1.3.[7]

The remaining parameters we set to values common in the literature. We set the intertemporal elasticity of substitution, $1/\gamma$, to 0.6 to match the mean estimate of studies of the US collected by Havranek et al. (2015). We set the Frisch elasticity, $1/\eta$, to 0.82, matching the estimate based on a meta analysis of studies using microdata in Chetty et al. (2011). We set the Taylor rule coefficients to $\phi_\pi = 1.5$ and $\phi_y = 0.125$, corresponding to a response of the annualised rate to the output gap of 0.5 (Taylor, 1993). We set the probability of wage changes, $1 - \theta$, to 0.185, matching the quarterly frequency of wage increases found in Grigsby et al. (2021). Following Auclert et al. (2018), we set the union mark-up to the limiting case $\mu \to 1$, which means that we do not need to account for union profits in the model. We set the persistence of the preference shock to $\rho = 0.5$.

[7]From (6), $\psi = \frac{-\%\Delta G_t}{\%\Delta D_t} \frac{4\bar{G}}{\bar{D}}$, where $4\bar{G}$ is annualised steady state purchases.

Parameter	Description	Value	Target
β	Discount factor	0.993	Treasury bill yield
T	Government transfers	0.05	CBO, 2023
τ	Labour tax rate	0.2	CBO, 2023
$\bar{D}$	Steady state debt (quarterly output)	4	CBO, 2023
ζ	Short-term share of debt	0.3	US Treasury, 2023
δ	Bond decay rate	0.97	Mitra and Sack, 2022
$1/\gamma$	IES	0.6	Havranek et al., 2015
$1/\eta$	Frisch elasticity	0.82	Chetty et al., 2011
ϕ_π	Taylor rule, inflation	1.5	Taylor, 1993
ϕ_y	Taylor rule, output	0.125	Taylor, 1993
$1-\theta$	Calvo adjustment probability	0.185	Grigsby et al., 2021
μ	Union mark-up	1	
ρ	Preference shock persistence	0.5	
ψ	Fiscal adjustment	0.16	Section 3.1

Table 1: Calibration

4 Macroeconomic and policy implications

4.1 Quantitative easing calibration

Under quantitative easing policies, central banks purchase long-term government bonds from the private sector. These purchases are made through the creation of new interest bearing reserves held at the central bank. Large holdings of fixed rate assets matched by floating rate liabilities have meant that a number of central banks have experienced earnings losses, resulting in a reduction (or sometimes reversal) of payments from the central bank to the treasury. From the perspective of the government's consolidated balance sheet, quantitative easing policies amount to a fixed-for-floating swap, where the government pays the floating rate and receives a fixed rate, shortening the maturity profile of government debt.

In the US, Federal Reserve assets peaked at around $9 trillion in April 2022, composed predominantly of Treasury securities and mortgage backed securities, which is a little over one quarter of the value of federal debt. In our empirical calibration, we also consider an additional steady state where one quarter of total government debt is swapped into the short term asset. This lowers the weighted average duration of debt from 5 years to 3.5 years, in line with the weighted average duration for the US government with and without adjusting for the Federal Reserve System Open Market Account (Mitra and Sack, 2022). We consider two versions: a consolidated QE calibration, in which the swap is into the short-term bond so that central bank income passes through to the fiscal authority immediately, and an unconsolidated QE calibration, in which the central bank holds the long-term bonds,

financed by reserves, and follows the remittance rule (12) with $\vartheta = 0.01$.

4.2 Monetary policy transmission

Figure 3 shows the effect of a monetary policy shock in the model. The figure shows impulse response functions from a first order perturbation around the steady state. The increase in the interest rate leads to an immediate fall in consumption as the household is induced to delay consumption due to a higher return on savings. The rise in the interest rate also increases borrowing costs for the government, resulting in a persistent fall in government purchases and a persistent increase in debt. The reduction in government purchases directly reduces output through reduced public demand. However, the effect on output is small because of the calibrated size and duration of debt.

The QE calibrations amplify the fiscal adjustment: the higher share of short term debt makes the government's budget constraint more sensitive to the interest rate shock. When all losses are immediately passed through to the fiscal authority, this leads to a larger fall in purchases, but again the effect on output is small. When instead the monetary authority issues more reserves to cover its interest costs, the short-term effect on purchases and output compared to the calibration without QE is negligible, but debt remains persistently higher as increased interest costs are covered by newly issued reserves.

4.3 The role of the budget adjustment parameter ψ

Figure 4 shows the importance of the budget adjustment parameter, ψ, in the model. Lower values of ψ imply a large, persistent increase in debt, so that most of the effect of a monetary policy shock is from a contemporaneous drop in consumption. Conversely, when the government mostly responds to interest rate shocks by cutting spending, there is a large output response from a fall in public demand.

In our calibration, we set ψ to match the relative responses of debt and government purchases to monetary policy shocks in the data. However, ψ reflects a policy choice by the fiscal authority, so its empirical counterpart is likely to be time-varying and influenced by political and institutional features. Prior literature on monetary-fiscal interactions has emphasised that policy regimes appear to be time-varying (Davig and Leeper, 2011, Fernández-Villaverde et al., 2015, Bianchi and Melosi, 2017). From the perspective of central bank policymakers, time variation in fiscal rules could introduce significant uncertainty in the transmission of monetary policy. There is also likely to be substantial variation between countries. For example, as argued by Reichlin et al. (2023), monetary-fiscal interactions in the euro area are shaped by fiscal rules limiting debt and deficits.

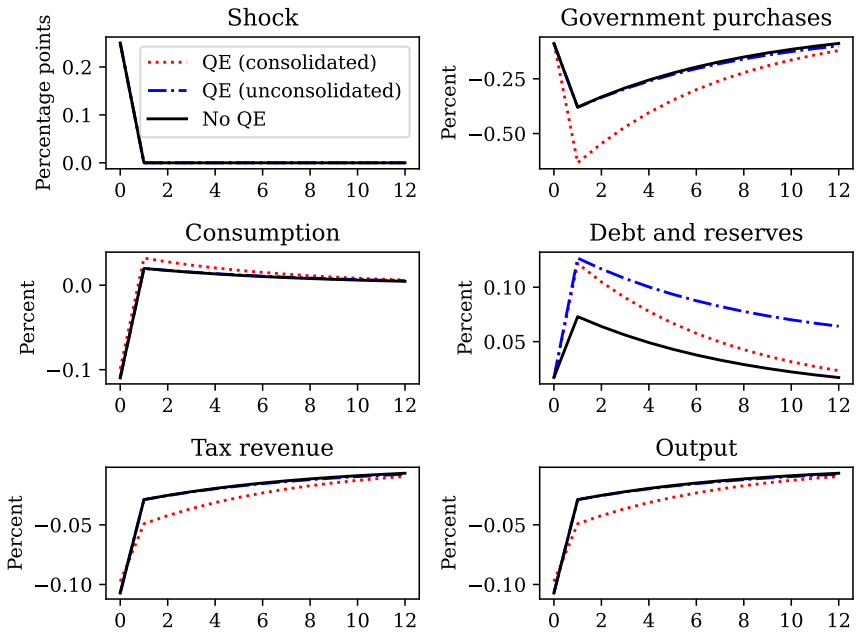


Figure 3: Impulse responses to a 25 basis point shock to the quarterly interest rate

Note: Impulse responses using the calibration outlined in Table 1 and Section 4.1. The consolidated QE calibration has 25 per cent of the stock of debt swapped into the short term bond. The unconsolidated QE calibration has 25 per cent of the stock of debt swapped into reserves and $\vartheta = 0.01$. The shock series is measured in percentage point deviations from steady state. All other series are percent deviations from steady state.

5 Government debt maturity structure and welfare

In this section we study how the maturity of government debt affects welfare. We first define welfare as a second-order approximation around an efficient steady state of the discounted infinite sum of utility of households. We show that welfare can be expressed in terms of losses due to fluctuations in inflation, in the output gap, and in the fiscal gap. The latter captures the fact that there exists an optimal allocation of resources between private and public consumption. Then, we close the economy by assuming that the central bank follows a standard Taylor rule, and we study how welfare depends on the fraction of short-term debt. Finally, we solve for the optimal policy under commitment and study welfare when interest rates are set optimally.

5.1 Definition of welfare

Following Clarida et al. (1999) and Woodford (2003) we define welfare losses as the fluctuations around an efficient steady state. Given that fluctuations in government consumption are at the core of our model, we assume that public spending enters the utility function of

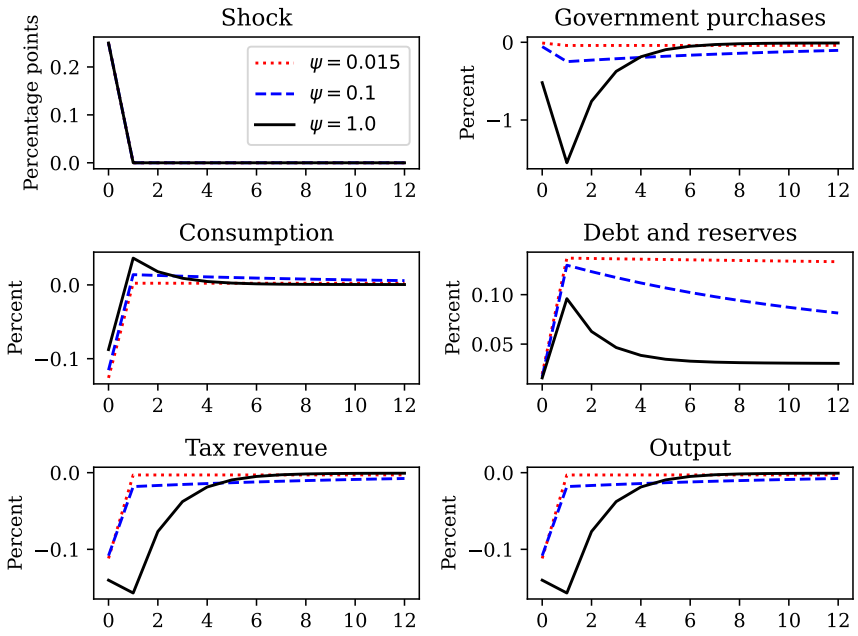


Figure 4: Impulse responses to a 25 basis point shock to the quarterly interest rate.

Note: Impulse responses using the unconsolidated QE calibration outlined in Table 1 and Section 4.1, with $\vartheta = 0.01$, for different values of ψ. The shock series is measured in percentage point deviations from steady state. All other series are percent deviations from steady state.

households, so that a positive quantity of spending is efficient. We follow Galí and Monacelli (2008) to derive a second order-approximation of welfare around an efficient steady state in which households derive utility from private and public consumption, and disutility from working hours.

As in Section 2, the utility function of the representative household is

$$U_t(C_t, G_t, H_t; \epsilon_t^d) = \left\{ (1-\chi)\frac{C_t^{1-\gamma}}{1-\gamma} + \chi\frac{G_t^{1-\gamma}}{1-\gamma} - \nu\frac{H_t^{1+\eta}}{1+\eta} \right\} e^{\epsilon_t^d}$$

where γ is constant relative risk aversion, η is the inverse Frisch elasticity, and the parameters χ and ν determine the relative preference over the different components of utility. $e^{\epsilon_t^d}$ is a preference shock.

We study the case of an efficient steady state. Efficiency requires that there is an efficient substitution between consumption and leisure, meaning that in steady state the marginal utility of consumption and the marginal disutility of labor must be equal,

$$(1-\chi)C^{-\gamma} = \nu H^{\eta}.$$

This condition is met by assuming that the government pays a subsidy Φ on labor supply to unions, which offsets the steady state distortions of market power and distortionary taxation, $1+\Phi = \frac{\mu}{1-\tau}$. Additionally, there must be an efficient substitution between private and public consumption,

$$(1-\chi)C^{-\gamma} = \chi G^{-\gamma}.$$

which implies that the efficient public spending-to-GDP ratio is:

$$\frac{G}{Y} = \frac{1}{1+\left(\frac{1-\chi}{\chi}\right)^{1/\gamma}},$$

For a given preference parameter χ, we assume that the government sets the steady-state level of government purchases to meet this condition.

Welfare at time 0 is defined as the infinite discounted sum of households' utility,

$$\tilde{W} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U_t(C_t, G_t, H_t; \epsilon_t^d).$$

We work with a second-order approximation of welfare around an efficient steady state. An approximation of welfare (defined as W, and expressed in terms of equivalent permanent consumption loss) can be expressed as the sum of welfare losses due to fluctuations in inflation π_t, in the output gap $\hat{y}_t$ and in the fiscal gap $(\hat{y}_t - \hat{g}_t)$:

$$W \propto \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{U_t - U}{U_c C}\right) = -\frac{1}{2C}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\underbrace{\pi_t^2}_{\text{inflation}} + \Xi(\gamma+\eta) \underbrace{\hat{y}_t^2}_{\text{output gap}} + \Xi\gamma\frac{G}{C} \underbrace{(\hat{y}_t - \hat{g}_t)^2}_{\text{fiscal gap}} \right) \tag{14}$$

where variables with a "hat" denote log-deviations from steady state. Ξ denotes the weight on terms other than inflation. While the presence of inflation and the output gap in the determination of welfare is standard, the fiscal gap captures the fact that it is not enough to close the output gap to maximize welfare, as there must be also an efficient allocation of resources between private and public consumption, and thus an optimal public spending to GDP ratio $\frac{G}{Y}$. In appendix A we show how to derive the expression above.

5.2 Log-linearized model

Since we use a second-order approximation of welfare around an efficient steady state, welfare losses are a function only of quadratic terms. First-order terms do not appear because the steady state is efficient. Therefore, in the model's equations only first-order terms matter

for welfare, as any term of order greater than 1 generates terms of order greater than 2, once they enter the second-order approximation of welfare. Therefore, we can work with a log-linearized version of the model. The first-order conditions of the household problem can be approximated to:

$$\hat{c}_t = \mathbb{E}_t\, \hat{c}_{t+1} - \frac{1}{\gamma}(\hat{i}_t - \mathbb{E}_t\, \pi_{t+1}) + \epsilon_t^d \tag{15}$$

$$\hat{q}_t = \beta\delta\, \mathbb{E}_t\, \hat{q}_{t+1} - \hat{i}_t \tag{16}$$

Flexible prices and sticky wages give a standard New-Keynesian Phillips curve:

$$\pi_t = \beta\, \mathbb{E}_t\, \pi_{t+1} + \kappa\, (\eta \hat{y}_t + \gamma \hat{c}_t) \tag{17}$$

Finally, combining the fiscal rules with the fiscal budget, we can approximate the fiscal block equilibrium conditions as:

Fiscal budget

$$\begin{aligned} G(1+1/\psi)\hat{g}_t = {} & \underbrace{\tau Y \hat{y}_t}_{\text{Tax revenues}} \quad \underbrace{-\zeta D(1+r)\hat{r}_{t-1}}_{\text{Interest of ST debt}} \underbrace{-(1-\zeta)D(1+r-\delta)(\hat{b}_{t-1} - \mathbb{E}_{t-1}\,\pi_t)}_{\text{Coupons of LT debt}} + \\ & + \underbrace{(\zeta(1+r) + (1-\zeta)(1+r-\delta))D \cdot (\pi_t - \mathbb{E}_{t-1}\,\pi_t)}_{\text{Surprise inflation on maturing assets}} + \quad \underbrace{\delta(1-\zeta)D \cdot \pi_t}_{\text{Inflation erodes outstanding debt}} \quad + \\ & + ((1-\zeta)\delta + \zeta(1+r)) \quad \underbrace{\frac{G}{\psi}\hat{g}_{t-1}}_{\text{Past debt:} -(D_{t-1}-D)} \end{aligned} \tag{18}$$

Law of motion of coupons

$$\hat{b}_t = \delta \hat{b}_{t-1} - (1-\delta)\hat{q}_t \underbrace{- \frac{G}{D\psi}(\hat{g}_t - \delta \hat{g}_{t-1})}_{\hat{d}_t - \delta \hat{d}_{t-1}} \tag{19}$$

where $\hat{r}_{t-1} \equiv \hat{i}_{t-1} - \mathbb{E}_{t-1}\,\pi_t$ is the ex-ante expected real interest rate. Equation (18) pins down public spending. Higher tax revenues allow for more spending, while higher real interest payments require spending cuts. Inflation erodes maturing assets via surprise inflation, but it also reduces the real value of the outstanding long-term debt. The sum of the two terms of inflation gives $D(1+r)\pi_t$, meaning that inflation relaxes the fiscal budget independently of debt maturity. Finally, the last term captures the fact that higher debt in the past requires spending cuts today, to repay the debt. Equation (19) is the law of motion of nominal

coupons, which is a slow moving process with auto-regressive coefficient δ.

5.3 Welfare under a Taylor rule

In this section we study how the maturity of government debt matters for welfare, when the central bank follows the Taylor rule (13) with the coefficients in Table 1:

$$\hat{i}_t = 1.5 \cdot \pi_t + 0.125 \cdot \hat{y}_t \tag{20}$$

We shock the economy with a preference shock of 25 basis points on impact, and persistence $\rho = 0.5$. We compare three scenarios that differ in the share of short-term debt ζ.

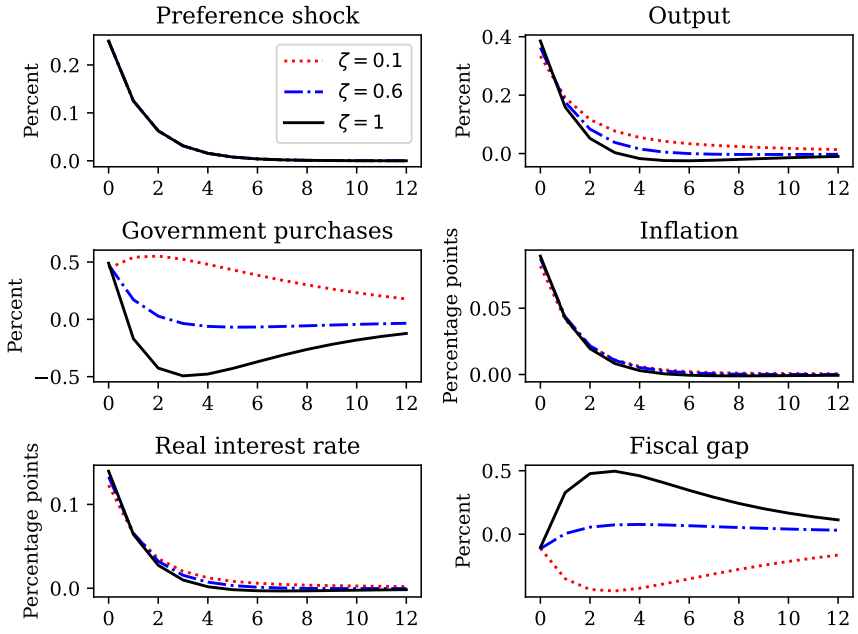


Figure 5: Demand shock - Standard Taylor rule - IRFs

Note: Impulse responses to a 25 basis point preference shock with persistence $\rho = 0.5$, using the calibration in Table 1 and the Taylor rule with $\phi_\pi = 1.5$ and $\phi_y = 0.125$, for different fractions of short-term debt ζ. Inflation and the real interest rate are measured in percentage point deviations from steady state. All other series are percent deviations from steady state.

The demand shock implies a relaxation of the fiscal budget because of inflation and higher tax revenues, which generate a rise in public spending. The central bank raises interest rates to dampen the economic boom and inflation. The red line in figure 5 shows the response of the economy when debt is mostly long-term. The rise in the real interest rate does not have a strong impact on the fiscal budget so public spending remains high, implying a large negative fiscal gap: there is too much production, and conditionally on that, too much public

spending. When we introduce some short-term debt (blue line), the rise in interest rates not only reduces consumption, but it also tightens the fiscal budget limiting the inefficient spike in public spending. The fiscal gap closes, and the lower public spending also allows for a lower output gap after the first quarter. Finally, there can also be too much short-term debt, as illustrated by the black line. When most debt is short-term, the rise in interest rates tightens the fiscal budget too much, and the drop in public spending generates a positive fiscal gap and causes output to overshoot below steady state.

In Figure 6 we plot welfare after a demand shock as a function of the fraction of short-term debt ζ. Welfare is hump-shaped in ζ: under the baseline fiscal rule it peaks at around 50 per cent short-term debt, and under a balanced budget at around 25 per cent.

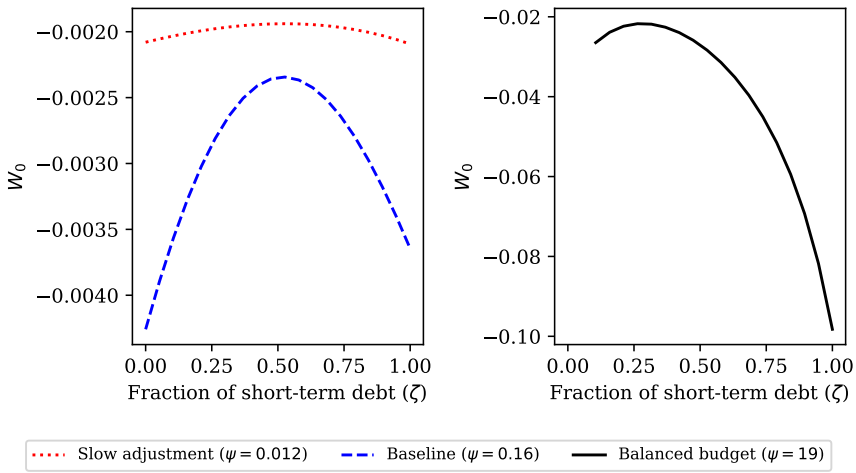


Figure 6: Welfare after a demand shock - standard Taylor rule

Note: Welfare after a 25 basis point preference shock under the Taylor rule, as a function of the fraction of short-term debt ζ, for slow adjustment ($\psi = 0.012$), the baseline fiscal rule ($\psi = 0.16$) and a balanced budget ($\psi = 19$). W_0 is the permanent consumption-equivalent welfare loss, in basis points of steady-state consumption. Under a balanced budget the model is indeterminate for $\zeta \leq 0.05$.

5.4 Welfare under optimal policy

In this section we derive the optimal policy under commitment and study the welfare implications of debt's maturity. The optimal policy can be found by solving the following Ramsey problem. At time 0, the central bank maximizes welfare (14) subject to economy's equilibrium conditions (15), (16), (17), (18) and (19). The first-order conditions to this problem specify the optimal response of the central bank under commitment from an intertemporal perspective. Combining the FOCs with the model's equilibrium condition, we find the solution under optimal policy. In appendix B we spell out the Ramsey problem in more

details.

In figure 7 we show the impulse response function of the economy after a preference shock, when the central bank sets interest rates optimally. We compare three scenarios that differ in the fraction of short-term debt ζ.

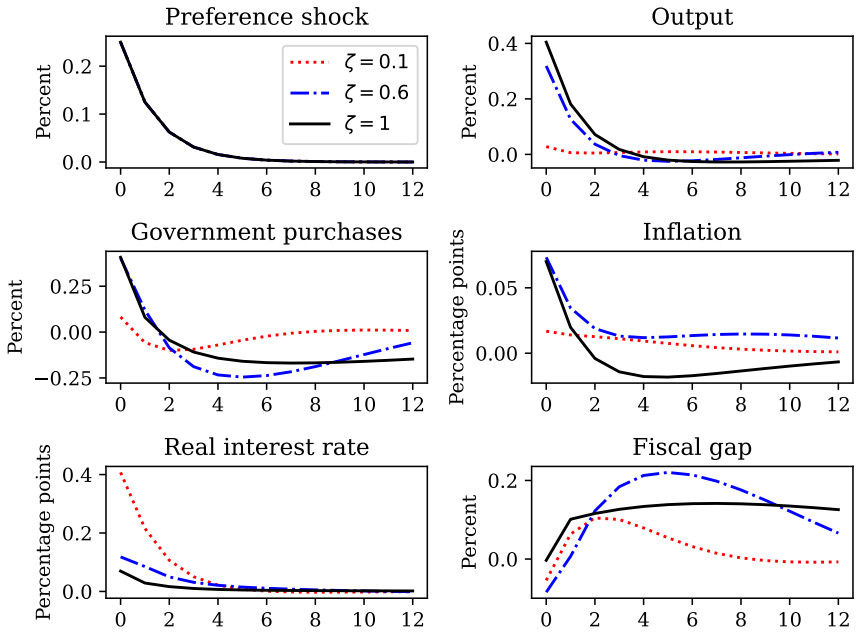


Figure 7: Demand shock - optimal policy under commitment - IRFs

Note: Impulse responses to a 25 basis point preference shock with persistence $\rho = 0.5$, using the calibration in Table 1, with interest rates set optimally under commitment, for different fractions of short-term debt ζ. Inflation and the real interest rate are measured in percentage point deviations from steady state. All other series are percent deviations from steady state.

Consider the economy with mostly short-term debt (black line). Studying the fiscal block in the limit case of only short-term debt $\zeta = 1$, we can observe that spending responds much to the real interest rate.

$$G\left(1 + 1/\psi\right)\hat{g}_t = \tau Y \hat{y}_t - D(1+r)\left(\hat{i}_{t-1} - \pi_t\right) + (1+r)\frac{G}{\psi}\hat{g}_{t-1} \qquad \forall t > 0$$

Therefore, the central bank cannot address the demand shock by raising interest rates too much, as it would generate large inefficient fluctuations in public spending. It is better to raise interest rates by a little but persistently, thus promising a recession in the mid-run.

Now consider the case in which there is mostly long-term debt (red line). The fiscal block with $\zeta = 0$ boils down to:

$$G\left(1 + 1/\psi\right)\hat{g}_t = \tau Y \hat{y}_t - D(1+r-\delta)\hat{b}_{t-1} + D(1+r)\pi_t + \delta\frac{G}{\psi}\hat{g}_{t-1} \qquad \forall t > 0$$

When there is only long-term debt, the real interest rate has little impact on the fiscal budget, as the nominal interest payments of the government follow the slow law of motion of $\hat{b}_t$. At the same time, the government is more subject to fluctuations in inflation, because the policy rate has only a muted effect on the nominal interest payments of the government (unlike in the case of only short-term debt). Therefore, it is optimal to respond to the demand shock only by raising interest rates on impact, without promising any future recession. A contraction in the mid-run would cause deflation and imply excessively large real interest payments. In other words, the fiscal budget in the mid-run would be tightened too much. The spike in the real interest rate on impact does not generate excessive fiscal disruptions, thanks to the long maturity of government debt.

Finally, under the scenario in which government debt is a mix of short and long-term debt (blue line), the central bank follows a policy that combines the two different strategies described above.

In Figure 8, we show that how welfare is affected by debt maturity (varying ζ) depends on the calibration of the fiscal rule. Under the baseline fiscal rule welfare is minimized at the corner, with only short-term debt. Under a balanced budget, welfare is instead minimized when the government has a mix of short and long-term debt, at around 60 per cent short-term debt. In this case, the central bank finds itself in the middle of the two opposite strategies described above and it cannot follow efficiently either of the two. Raising interest rates on impact would generate too large fiscal disruptions today, while promising a contraction in the mid-run would imply excessive fiscal tightening then.

Under a balanced budget, however, more short-term debt beyond this point improves welfare: losses with only short-term debt are around 40 per cent smaller than at the minimum, although still far larger than with only long-term debt. Once most debt is short-term, the policy rate directly sets the government's nominal interest payments, so the central bank can follow a small but persistent tightening. Figures 9 and 10 in the appendix show that, for all three maturity structures, losses rise with the speed of fiscal adjustment ψ, and that fluctuations in the output gap account for most of the losses and for their increase in ζ under the baseline fiscal rule.

5.5 Balance sheet policies

In this section, we formalize why optimal (consolidated) government debt maturity may be studied jointly with optimal interest rate setting. The key intuition is that through balance sheet policies, the central bank is able to affect the average maturity of the consolidated government debt. Therefore, conditional on a fiscal rule of the government, the optimal

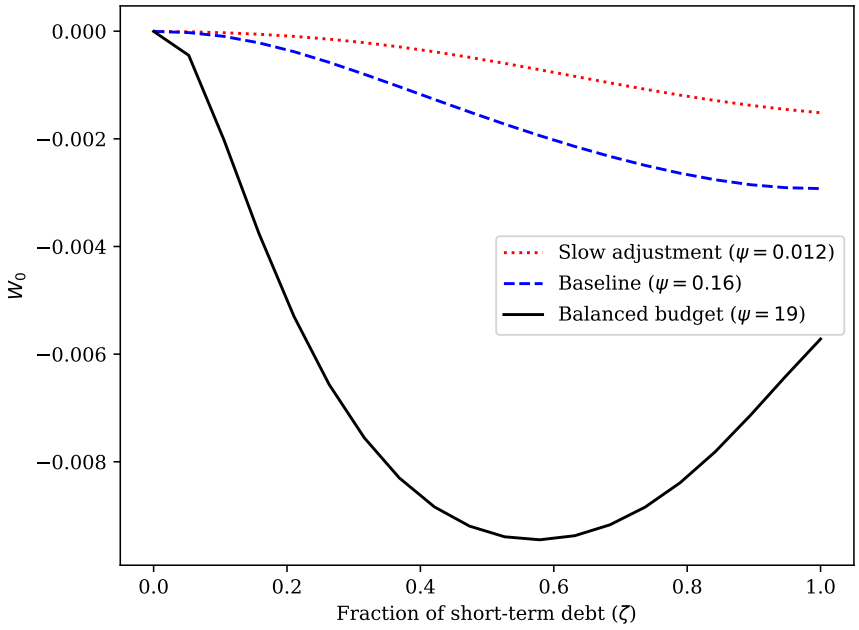


Figure 8: Welfare after a demand shock - optimal policy under commitment

Note: Welfare after a 25 basis point preference shock under optimal policy under commitment, as a function of the fraction of short-term debt ζ, for slow adjustment ($\psi = 0.012$), the baseline fiscal rule ($\psi = 0.16$) and a balanced budget ($\psi = 19$). W_0 is the permanent consumption-equivalent welfare loss, in basis points of steady-state consumption.

policy problem of the central bank can be specified as an optimal choice over debt maturity and interest rate setting.

Suppose that in steady state the central bank holds a stock of long-term Treasury bonds $\tilde{B}^c$. By combining the constant zero net worth rule (11) and the budget constraint of the central bank (8), up to a first-order approximation, government remittances are given by:

$$R_t - R = \tilde{B}^c(1 + r - \delta)\hat{b}^c_{t-1} - \tilde{B}^c(1 + r)\hat{i}_{t-1} \tag{21}$$

$$\hat{b}^c_t = \delta\hat{b}^c_{t-1} - (1 - \delta)\hat{q}_t \tag{22}$$

where $\hat{b}^c_t$ denotes the coupons earned on the central bank's bond holdings. A first observation is that inflation does not contribute to determining the real remittances, as it erodes assets and liabilities in the same way. Second, the new purchases of long-term Treasuries Z^c_t do not matter up to a first-order approximation, as the interaction between changes in interest rates and the maturity exposure of the government is a second-order moment. Our approximation is well-equipped to study small QE interventions, which only have second-order effects on the economy and thus may be ignored. We leave the study of large QE interventions for further research, as analyzing such policy would require formulating welfare in its fully non-linear

form.

Yet, even up to first-order, the inherited balance sheet (before a shock hits, i.e. the steady state) does matter. In fact, by combining the expression for remittances with the government budget, one can express the consolidated fiscal block as:

$$G(1+1/\psi)\hat{g}_t = \tau Y \hat{y}_t - \left[\zeta D + \tilde{B}^c\right](1+r)\hat{i}_{t-1} - (1-\zeta)D(1+r-\delta)\hat{b}_{t-1} + \tilde{B}^c(1+r-\delta)\hat{b}^c_{t-1} + D(1+r)\pi_t + ((1-\zeta)\delta + \zeta(1+r))\frac{G}{\psi}\hat{g}_{t-1} \tag{23}$$

The central bank's holdings raise the exposure of the budget to the policy rate exactly as if the Treasury's short-term share were $\zeta + \tilde{B}^c/D$. Therefore, by choosing a stock of long-term Treasury bonds $\tilde{B}^c$, the central bank can influence the effective maturity structure of the consolidated government, and hence where the economy sits on the welfare curves in Figures 6 and 8.

6 Conclusion

Changes in interest rates affect the government's intertemporal budget constraint, necessitating some reaction from the fiscal authority. In the data, monetary policy shocks lead to a reduction in government purchases, lower tax revenues from the fall in activity, and an increase in debt issuance. Expanded central bank balance sheets imply a larger fiscal channel of monetary policy, since the large share of short term liabilities makes governments' consolidated balance sheets more sensitive to interest rate changes. When the central bank instead finances its losses by issuing reserves, the fiscal response is delayed and consolidated debt stays persistently higher.

More generally, the importance of the maturity structure of government debt points to a state dependence in monetary policy transmission as the maturity structure of government debt changes over time. For example, from 1980 until 2022 the weighted average maturity of (unconsolidated) US government debt increased from around three and a half years to over six years and the share of debt maturing within one year fell from just under 50 per cent to around 30 per cent (US Treasury, 2023). Similarly, the fiscal response to monetary policy shocks is also likely to be time varying as political and institutional constraints change over time.

The welfare consequences of a shorter maturity structure depend on how monetary policy is conducted. Under a Taylor rule, short-term debt dampens the response of public spending to demand shocks and welfare is maximised at an interior short-term share. Under optimal policy with commitment, long-term debt is best. Since central bank balance sheets shift the

effective maturity of consolidated debt, asset purchases are also a choice about where the economy sits along these welfare curves.

Our analysis relies on first-order approximations, so remittances respond symmetrically to central bank profits and losses. Further research could model alternative institutional structures, which are likely to be important in determining fiscal responses. For example, when facing losses the Federal Reserve initially enters a period of zero remittances, booking a claim against future remittances to the Treasury, which may affect the timing of the Treasury's fiscal adjustment.

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A Derivation of an approximation for welfare

In this section we derive equation (14). Galí (2015) can be used as a reference on how to derive such an approximation for a standard utility function, and Galí and Monacelli (2008) for the case in which public spending enters the utility function. In what follows we make use of the following second-order approximation of log-changes of a given variable, which are denoted with a hat:

$$\left(\frac{X_t - X}{X}\right) \approx \hat{x}_t + \frac{1}{2}\hat{x}_t^2$$

where $\hat{x}_t = \ln(X_t/X)$, and up to a second-order approximation $\left(\frac{X_t - X}{X}\right)^2 \approx \hat{x}_t^2$.

After plugging in the goods market clearing condition, utility is:

$$U_t = \left\{(1-\chi)\frac{(Y_t - G_t)^{1-\gamma}}{1-\gamma} + \chi\frac{G_t^{1-\gamma}}{1-\gamma} - \nu\frac{H_t^{1+\eta}}{1+\eta}\right\} e^{\epsilon_t^d}$$

A second-order approximation around the steady state of this expression gives:

$$\frac{U_t - U}{U_c} = Y\left(\hat{y}_t + \frac{1-\gamma\frac{Y}{C}}{2}\hat{y}_t^2\right) - \frac{1}{2}\gamma\left(\frac{YG}{C}\right)\hat{g}_t^2 + \gamma\left(\frac{YG}{C}\right)\hat{y}_t\hat{g}_t - Y\left(\hat{h}_t + \frac{1+\eta}{2}\hat{h}_t^2\right)$$

Following appendix 4.1 of Galí (2015), it can be shown that log-deviations in working hours are equal to the sum of the log-deviations in output and price dispersion d_t. A similar result holds in a model with sticky wages, where now it is the wage dispersion that matters:

$$\hat{h}_t = \hat{y}_t + d_t$$

where $d_t = \ln \int_0^1 \left(\frac{W_t(i)}{W_t}\right)^{-\mu/(\mu-1)} = \frac{1}{2}\frac{\mu}{\mu-1}\text{Var}_i(\ln W_t(i))$. The intuition is that for given output, wage dispersion implies an inefficient labor supply and thus more working hours. Ignoring moments of order higher than 2, we also have $\hat{h}_t^2 = \hat{y}_t^2$. Substituting in the approximation of the utility function, and under the normalization $Y = 1$, we get:

$$\begin{aligned}\frac{U_t - U}{U_c} &= -Y d_t - \frac{1}{2}(\eta + \gamma\frac{Y}{C})Y\hat{y}_t^2 - \frac{1}{2}\gamma\left(\frac{YG}{C}\right)\hat{g}_t^2 + \gamma\left(\frac{YG}{C}\right)\hat{y}_t\hat{g}_t \\ &= -\frac{1}{2}\frac{\mu}{\mu-1}\text{Var}_i(\ln W_t(i)) - \frac{1}{2}(\eta+\gamma)\hat{y}_t^2 - \frac{1}{2}\gamma\left(\frac{G}{C}\right)(\hat{y}_t - \hat{g}_t)^2\end{aligned}$$

Then, a second-order approximation of welfare is:

$$\begin{aligned}W &= \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{\frac{U_t - U}{U_c C}\right\} \\ &= -\frac{1}{2C}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{\frac{\mu}{\mu-1}\text{Var}_i(\ln W_t(i)) + (\eta+\gamma)\hat{y}_t^2 + \gamma\frac{G}{C}(\hat{y}_t - \hat{g}_t)^2\right\} \\ &= -\frac{1}{2C}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{\frac{\mu}{\mu-1}\frac{1}{\kappa}\pi_t^2 + (\gamma+\eta)\hat{y}_t^2 + \gamma\frac{G}{C}(\hat{y}_t - \hat{g}_t)^2\right\}\end{aligned}$$

where we have used a result from Woodford (2003): $\sum_{t=0}^{\infty}\beta^t \text{Var}_i(\ln W_t(i)) = \frac{1}{\kappa}\sum_{t=0}^{\infty}\beta^t\pi_t^2$, where $\kappa = \frac{(1-\theta\beta)(1-\theta)}{\theta}$ is the slope of the NKPC and under flexible prices price inflation is equal to wage inflation. Finally, we can define $\Xi = \frac{\mu-1}{\mu}\kappa$ and normalize by the weight of inflation. Therefore, welfare is proportional to:

$$W \propto -\frac{1}{2C}\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{\pi_t^2 + \Xi(\gamma+\eta)\hat{y}_t^2 + \Xi\gamma\frac{G}{C}(\hat{y}_t - \hat{g}_t)^2\right\}$$

proving equation (14). Welfare is expressed in terms of equivalent permanent consumption losses $U_c C$.

B Optimal policy under commitment

The central bank at time 0 solves the following Ramsey problem:

$$\max_{\{\hat{y}_t,\hat{g}_t,\hat{b}_t,\hat{q}_t,\hat{\pi}_t,\hat{i}_t\}_{t\in(0,\infty)}} W \propto -\frac{1}{2}\,\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\pi_t^2 + \Xi(\gamma+\eta)\hat{y}_t^2 + \Xi\gamma\frac{G}{C}(\hat{y}_t-\hat{g}_t)^2\right)$$

subject to:

$$G\,(1+1/\psi)\,\hat{g}_t = \tau Y \hat{y}_t - \zeta D(1+r)\hat{i}_{t-1} - (1-\zeta)D(1+r-\delta)\hat{b}_{t-1} + D(1+r)\pi_t + ((1-\zeta)\delta + \zeta(1+r))\frac{G}{\psi}\hat{g}_{t-1} \qquad (\lambda_t^g) \quad (24)$$

$$\hat{b}_t = \delta\hat{b}_{t-1} - (1-\delta)\hat{q}_t - \frac{G}{D\psi}(\hat{g}_t - \delta\hat{g}_{t-1}) \qquad (\lambda_t^b) \quad (25)$$

$$\frac{Y}{C}\hat{y}_t - \frac{G}{C}\hat{g}_t = \frac{Y}{C}\,\mathbb{E}\,\hat{y}_{t+1} - \frac{G}{C}\,\mathbb{E}\,\hat{g}_{t+1} - \frac{1}{\gamma}(\hat{i}_t - \mathbb{E}\,\pi_{t+1}) + \epsilon_t^d \qquad (\lambda_t^y) \quad (26)$$

$$\pi_t = \beta\,\mathbb{E}\,\pi_{t+1} + \kappa(\eta+\gamma\frac{Y}{C})\hat{y}_t - \kappa\gamma\frac{G}{C}\hat{g}_t \qquad (\lambda_t^p) \quad (27)$$

$$\hat{q}_t = \delta\beta\,\mathbb{E}\,\hat{q}_{t+1} - \hat{i}_t \qquad (\lambda_t^q) \quad (28)$$

where λ_t^j for $j = \{g, b, y, p, q\}$ are the Lagrange multipliers of each equilibrium condition.

The FOCs to this problem are:

$$(\hat{y}_t) \qquad -\Xi(\gamma+\eta)\hat{y}_t - \Xi\gamma\frac{G}{C}(\hat{y}_t-\hat{g}_t) + \tau Y\lambda_t^g - \frac{Y}{C}\lambda_t^y + \frac{Y}{\beta C}\lambda_{t-1}^y + \kappa(\eta+\gamma\frac{Y}{C})\lambda_t^p = 0 \quad (29)$$

$$(\hat{g}_t) \qquad \Xi\gamma\frac{G}{C}(\hat{y}_t-\hat{g}_t) - G\left(1+\frac{1}{\psi}\right)\lambda_t^g + \beta((1-\zeta)\delta+\zeta(1+r))\frac{G}{\psi}\,\mathbb{E}_t\,\lambda_{t+1}^g - \frac{G}{D\psi}\lambda_t^b + \quad (30)$$

$$+\beta\delta\frac{G}{D\psi}\,\mathbb{E}_t\,\lambda_{t+1}^b + \frac{G}{C}\lambda_t^y - \frac{G}{\beta C}\lambda_{t-1}^y - \kappa\gamma\frac{G}{C}\lambda_t^p = 0 \quad (31)$$

$$(\hat{b}_t) \qquad \lambda_t^b = \beta\delta\,\mathbb{E}\,\lambda_{t+1}^b - \beta(1-\zeta)D(1+r-\delta)\,\mathbb{E}\,\lambda_{t+1}^g \quad (32)$$

$$(\hat{q}_t) \qquad \lambda_t^q = \delta\lambda_{t-1}^q - (1-\delta)\lambda_t^b \quad (33)$$

$$(\hat{\pi}_t) \qquad -\pi_t - \lambda_t^p + \lambda_{t-1}^p + \frac{1}{\gamma\beta}\lambda_{t-1}^y + D(1+r)\lambda_t^g = 0 \quad (34)$$

$$(\hat{i}_t) \qquad -\beta\zeta D(1+r)\,\mathbb{E}\,\lambda_{t+1}^g - \frac{1}{\gamma}\lambda_t^y - \lambda_t^q = 0 \quad (35)$$

Solving the five constraints together with these six first-order conditions, one can find the model's solution with optimal policy under commitment.

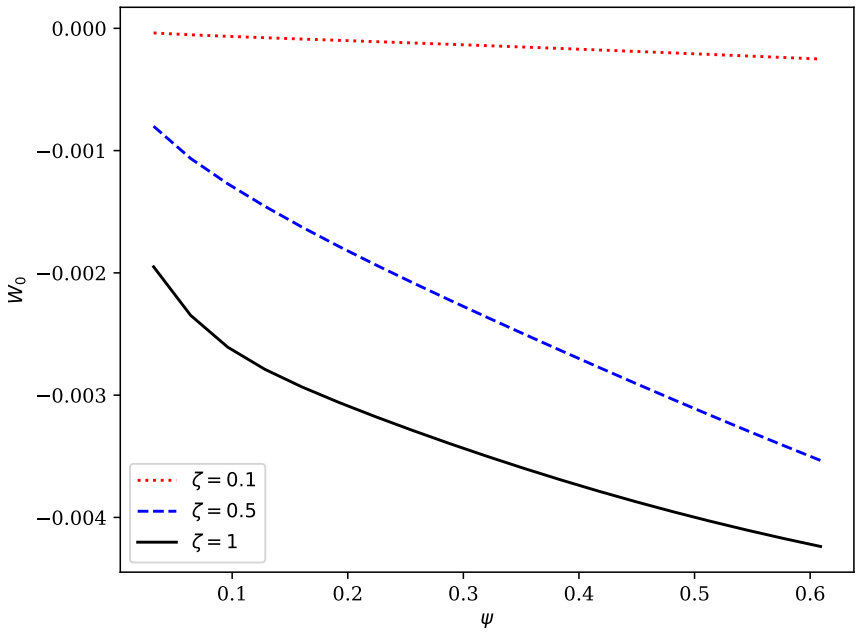


Figure 9: Welfare after a demand shock - optimal policy under commitment - over ψ

Note: Welfare after a 25 basis point preference shock under optimal policy under commitment, as a function of the fiscal adjustment parameter ψ, for different fractions of short-term debt ζ. W_0 is the permanent consumption-equivalent welfare loss, in basis points of steady-state consumption.

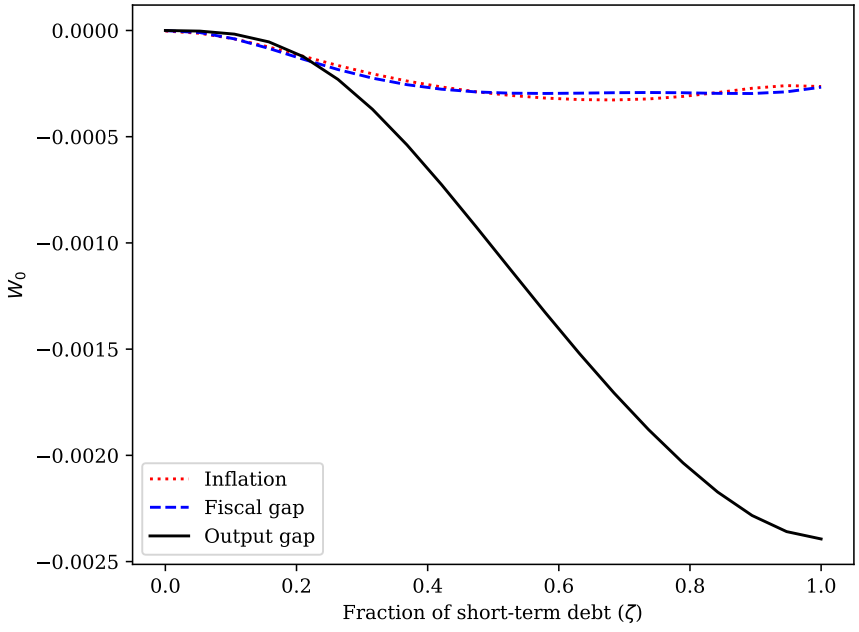


Figure 10: Welfare after a demand shock - optimal policy under commitment - decomposition

Note: Contributions of inflation, the output gap and the fiscal gap to welfare after a 25 basis point preference shock under optimal policy under commitment, with the baseline fiscal rule ($\psi = 0.16$). W_0 is the permanent consumption-equivalent welfare loss, in basis points of steady-state consumption.