

# Fiscal Adjustment to Monetary Shocks<sup>\*</sup>

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## Abstract

How does the fiscal side of the US government react to monetary policy? I estimate the response of several fiscal variables to monetary shocks. Following an interest rate hike, tax receipts fall, outlays excluding interest payments are constant, and interest payments and debt increase. The fall in output that follows a monetary tightening — not legislated changes in marginal tax rates — drives the response of receipts. The fiscal authority therefore responds passively to monetary shocks, keeping expenditures constant and letting debt adjust to satisfy its budget constraint. In heterogeneous agent models, this scenario dampens output’s response to monetary policy.

**Keywords:** fiscal policy, monetary policy, heterogeneous agent models

**JEL codes:** E52, E63, H30, H60

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<sup>\*</sup>An appendix is available on my web page: <https://www.paul-bouscasse.com>.

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# 1 Introduction

In heterogeneous agent new Keynesian (HANK) models, the effect of a monetary policy shock on the economy sharply depends on how the fiscal side of the government reacts (Kaplan et al., 2018, Alves et al., 2020). An interest rate hike increases payments on public debt, thus deteriorating the budget balance. Whether the fiscal authority clears its budget constraint by changing income taxes, transfers, spending or issuing more debt, shapes the response of output because it shifts the burden of adjustment to different households. Yet little empirical evidence exists on how Congress responds to the Federal Open Market Committee’s (FOMC) decisions.

To answer that question, I estimate the response of several fiscal variables to monetary policy shocks constructed in the spirit of Romer and Romer (2004). These shocks are interest rate changes purged from forecasts of output, inflation and unemployment prepared by the staff of the Federal Reserve System. Since the FOMC might react to news about future fiscal policy, I purge rate changes from forecasts of government receipts, expenditures and surpluses as well. Then, I estimate the effect of those shocks on tax receipts, outlays, debt and surpluses at the federal level. The data on fiscal variables was manually collected from the *Treasury Bulletin*.

I find that, following an exogenous monetary policy tightening, receipts decrease, outlays excluding interest payments are constant, and interest payments and debt increase — all of these variables being expressed in real terms. For a hundred basis point increase in the federal funds rate (FFR) target, tax receipts fall by about 2% within two years and bounce back after two more years. Using a database on legislated tax changes (Romer and Romer, 2010), I show that this response is not driven by legislated changes in the tax schedule, but by the endogenous reaction of tax receipts to the fall in output. Perhaps surprisingly, government transfer payments do not exhibit any response. The explanation is simple: most transfers, such as Social Security and Medicare, are not automatic stabilizers. Unemployment insurance is, but it only accounts for a small share of transfers paid by the federal government.

With receipts falling, roughly constant expenditures, and increased interest rate payments, the budget balance deteriorates and feeds an increase in federal debt.

Finally, I show that a simple model of government behavior and debt dynamics can generate these impulse response functions. An ingredient of the model is important to match the response of interest payments: long-term debt. Indeed, a model with only short-term debt would imply that interest payments react in proportion to the interest rate. With an initial interest rate of 6% — the average FFR from 1969 to 2007 —, interest rate payments would jump, in such a model, by 17% following a 100 basis points increase in the nominal interest rate. My empirical findings suggest a much milder response, 5% at the most. Thus, incorporating a realistic maturity structure of government debt into HANK models may also matter to their predictions, because said structure determines the size of the required fiscal adjustment.

**Related literature:** Kaplan et al. (2018) lament that “there is no empirical evidence that reveals what type of fiscal adjustment is the most likely to occur in practice, following a monetary shock”. Still, some papers have touched this question *en passant*. Using vector autoregression (VAR) shocks, Cochrane (1999) finds “not a shred of statistical evidence that federal-funds shocks forecast surpluses”. Using a VAR with high-frequency shocks, Sterk and Tenreyro (2018) estimate a response of real debt that is roughly consistent with mine. Also using a VAR with high-frequency shocks, Caramp and Silva (2018) find that fiscal revenues over GDP fall after a monetary shock, government purchases are constant and transfers slightly increase. In spirit, my paper draws on Coibion et al. (2017), who estimate the response of consumption inequality to Romer and Romer-style shocks, and seek to provide stylized facts for heterogeneous agent models.

## 2 Methodology

### 2.1 Estimation Strategy

To identify monetary shocks, I use a variation on the measure developed by Romer and Romer (2004), henceforth RR. RR purge rate changes from forecasts of output, inflation and unemployment to remove the component of monetary policy that is endogenous to economic conditions. The forecasts they use, known as the Greenbook forecasts, are prepared before each Federal Open Market Committee (FOMC) meeting by the staff of the Federal Reserve.

It is plausible, however, that the monetary side of the US government should systematically react to the stance of its fiscal side, above and beyond the latter's effect on output, inflation and unemployment. For instance, the FOMC may monetize fiscal deficits, or tighten in the face of those deficits as a show of independence. To mitigate this concern, I add Greenbook forecasts for receipts, expenditures and surplus of the federal government to the list of controls. Thus, I estimate:

$$\begin{aligned}
\Delta i_m = & \alpha + \beta i_{m-1} + \sum_{q=-1}^2 \gamma^q \Delta \tilde{y}_m^q + \sum_{q=-1}^2 \zeta^q (\Delta \tilde{y}_m^q - \Delta \tilde{y}_{m-1}^q) \\
& + \sum_{q=-1}^2 \eta^q \tilde{\pi}_m^q + \sum_{q=-1}^2 \theta^q (\tilde{\pi}_m^q - \tilde{\pi}_{m-1}^q) + \iota \tilde{u}_m^0 \\
& + \sum_{q=-1}^2 \kappa^q \Delta \tilde{r}\tilde{e}c_m^q + \sum_{q=-1}^2 \lambda^q (\Delta \tilde{r}\tilde{e}c_m^q - \Delta \tilde{r}\tilde{e}c_{m-1}^q) \\
& + \sum_{q=-1}^2 \mu^q \Delta \tilde{e}\tilde{x}p_m^q + \sum_{q=-1}^2 \nu^q (\Delta \tilde{e}\tilde{x}p_m^q - \Delta \tilde{e}\tilde{x}p_{m-1}^q) \\
& + \sum_{q=-1}^2 \pi^q \tilde{s}r\tilde{p}l_m^q + \sum_{q=-1}^2 \rho^q (\tilde{s}r\tilde{p}l_m^q - \tilde{s}r\tilde{p}l_{m-1}^q) + \epsilon_m
\end{aligned} \tag{1}$$

where  $\Delta i_m$  is the change in the intended federal funds rate in meeting  $m$ , and  $\Delta \tilde{y}_m^q$ ,  $\tilde{\pi}_m^q$ ,  $\tilde{u}_m^q$ ,  $\Delta \tilde{r}\tilde{e}c_m^q$ ,  $\Delta \tilde{e}\tilde{x}p_m^q$  and  $\tilde{s}r\tilde{p}l_m^q$  are the forecasts for real output growth, inflation, unemployment, receipts growth, expenditures growth and total budget surplus as a share of output in the

previous ( $q = -1$ ), current ( $q = 0$ ) and subsequent ( $q = 1, 2$ ) quarters. The residuals obtained after running this regression,  $\hat{\epsilon}_m$ , are my measure of monetary shocks. Since there might be several monetary policy meetings in a given month, I sum the residuals within each month.

Following Jordà (2005) and Jordà et al. (2015), my main empirical specification is a local projection with instrumental variable (LP-IV):

$$y_{t+k} - y_{t-1} = \omega^k + \psi^k \Delta i_t + X'_{t-1} \chi^k + \xi_t^k \quad (2)$$

where  $y_t$  is the logarithm of the fiscal variable of interest in month  $t$ ,  $\Delta i_t$  the change in the effective FFR, and  $X_{t-1}$  is a vector of controls.  $\Delta i_t$  is instrumented with  $\hat{\epsilon}_t$ , the monthly sum of the residuals obtained after estimating equation (1). The controls are a quarter of lagged changes in industrial production and the consumer price index (CPI), as well as a quarter of lagged values of the unemployment rate, the FFR and the shocks. The impulse response function at horizon  $k$  is given by the various  $\psi^k$  for  $0 \leq k \leq K$ . Following Coibion et al. (2017), I estimate the system of equations jointly across horizons. Standard errors allow for heteroskedasticity, as well as correlation across horizons and time (Driscoll and Kraay, 1998).

## 2.2 Variables of Interest

The variables of interest are receipts, outlays excluding interest payments, interest payments and debt of the federal government. Receipts are mainly composed of income and social insurance taxes. Outlays are all payments made to liquidate an obligation other than the repayment of debt principal. Since that definition includes interest payments, I break them into outlays excluding interest payments and interest payments. Interest payments are defined as interest paid by the Treasury minus interest paid to government accounts. Debt is federal debt held by the public. I deflate each variable by the CPI, and express it in natural

logarithm.

Theoretical models usually distinguish government purchases of goods and services,<sup>1</sup> from transfers. Alas, this distinction is unknown to the *Treasury Bulletin*: these two categories are lumped together under outlays. In section 3.2.2, I will supplement the analysis with data from the NIPA tables and the *Monthly Treasury Statement*.

Up to accounting reconciliations, the following identity holds (in nominal terms):

$$\begin{aligned} \text{outlays} - \text{receipts} &= \Delta \text{ federal debt held by the public} \\ &\quad - \Delta \text{ monetary assets} \\ &\quad - \Delta \text{ other balances} \end{aligned} \tag{3}$$

Monetary assets are mainly Treasury operating cash, other balances include various accounts.<sup>2</sup> While these two items are sometimes non negligible, I focus on the evolution of debt as it closely matches accumulated deficit over time (figure 1).

Finally, I shall be interested in surpluses. Since a surplus can switch sign, I express it as a share of receipts instead of taking its logarithm:

$$\text{surplus} = \frac{\text{receipts} - \text{outlays}}{\text{receipts}}$$

This formula corresponds to the primary surplus if interest payments are excluded from outlays, to the total surplus otherwise.

## 2.3 Data

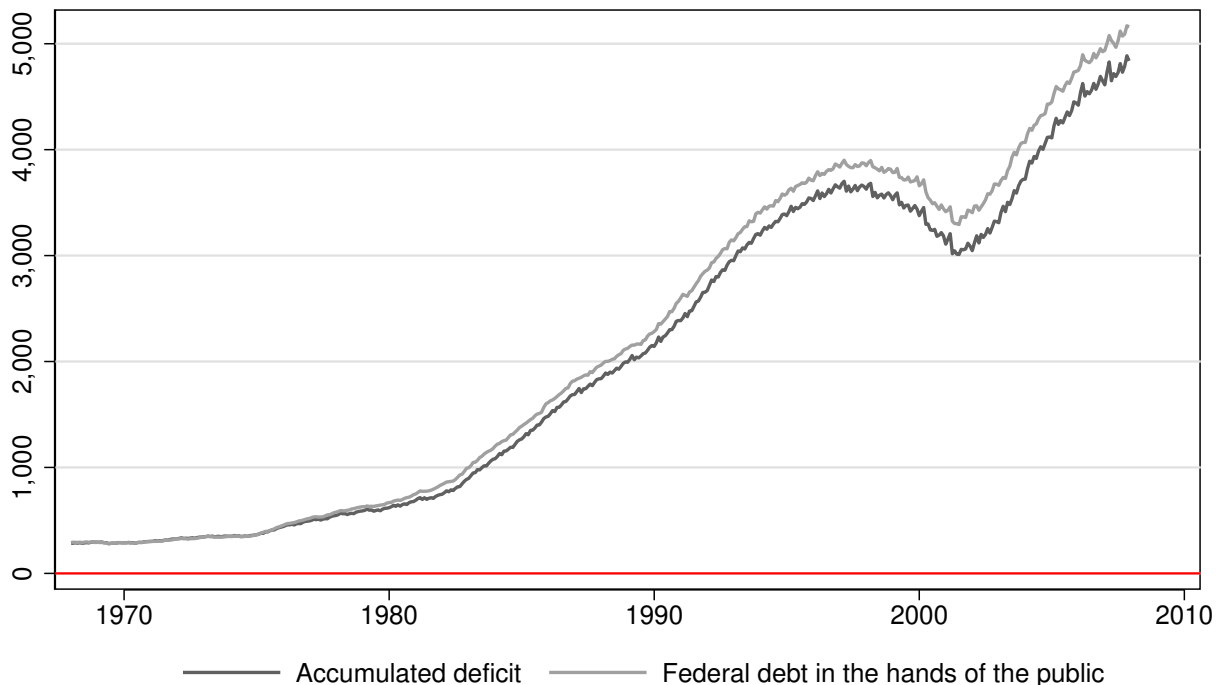
Especially before 1980, monthly fiscal data is not readily available in digital format. With the help of a research assistant, I hand-collected data from the *Treasury Bulletin* and the *Monthly*

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<sup>1</sup>Most papers use the term “spending”. I will use “purchases” in order to avoid the ambiguity of whether I am including transfers. Obviously, “purchases” include the purchase of labor services from civil servants, i.e. their salary. In national accounting, this is known as government consumption and investment.

<sup>2</sup>See White House - Office of Management and Budget (2018) for more details.

Figure 1: Deficit and debt over the long run



Note: expressed in billion dollars. Both series are equal in January 1970 by construction.

*Treasury Statement of Receipts and Outlays*.<sup>3</sup> Since this data displays extreme seasonal variations, I tame it with the Census Bureau's X-13ARIMA-SEATS — this is implemented in R thanks to the `seasonal` package. To avoid data mining suspicions, I did not seek to adjust the default configuration and let the software choose the specification.

I obtained the Greenbook forecasts from Coibion et al.'s (2017) and Croushore and van Norden's (2018) online appendices. The shock series start in March 1969, when the Greenbooks begin forecasting two quarters ahead, and ends in 2007, since the zero-lower bound became binding in 2008.

Effective FFR, industrial production, CPI and unemployment rate are standard series, downloaded from FRED.

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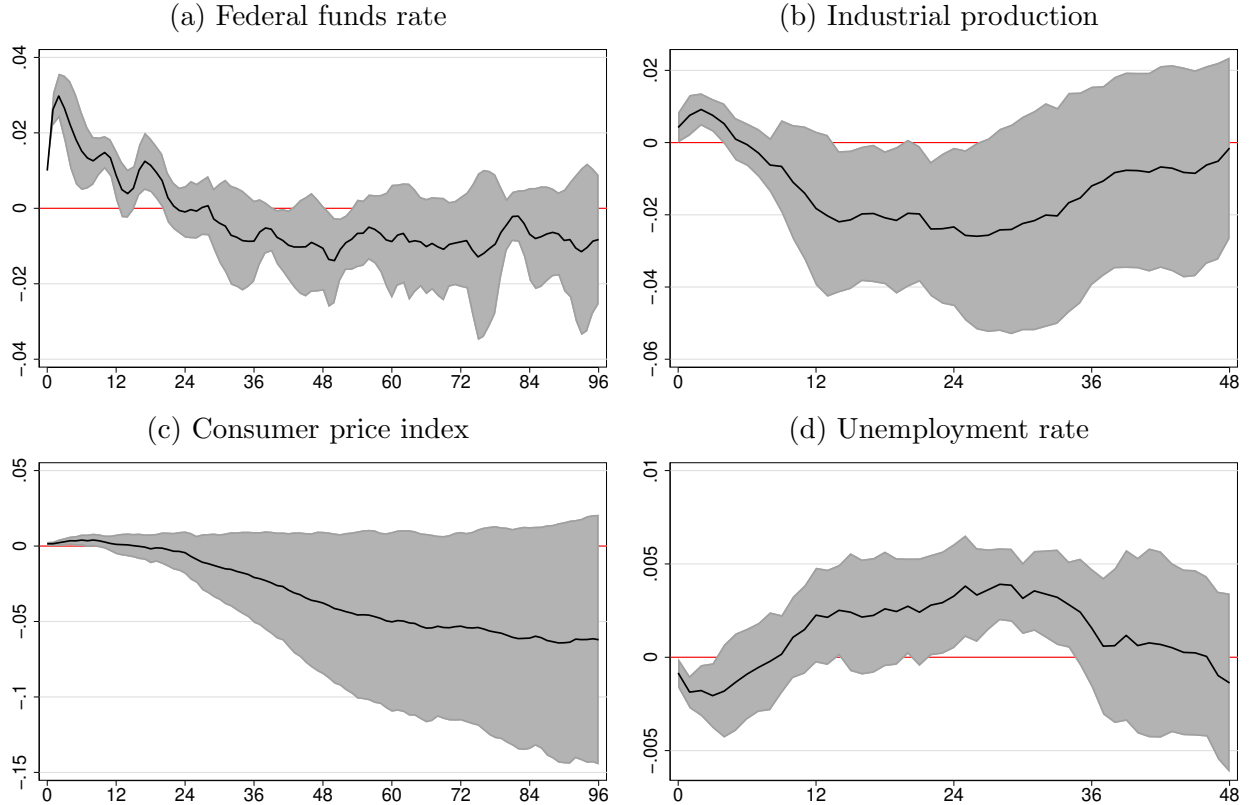
<sup>3</sup>Section B in the appendix contains precise references to the series used. A link to this appendix is available on the first page of this article.

### 3 Results

#### 3.1 Baseline

To give context, I first reproduce the well-known responses of the FFR, industrial production, the CPI and the unemployment rate after a RR-style shock (Ramey, 2016, Nakamura and Steinsson, 2018). These are shown in figure 2. The FFR increases by 100 basis points on impact, keeps increasing for a few months, and reverts to its initial value 20 months after the shock. Industrial production falls by about 2% within two years and bounces back within two additional years. The CPI falls by close to 4% in 4 years. The unemployment rate increases by up to 30 basis points.

Figure 2: Context



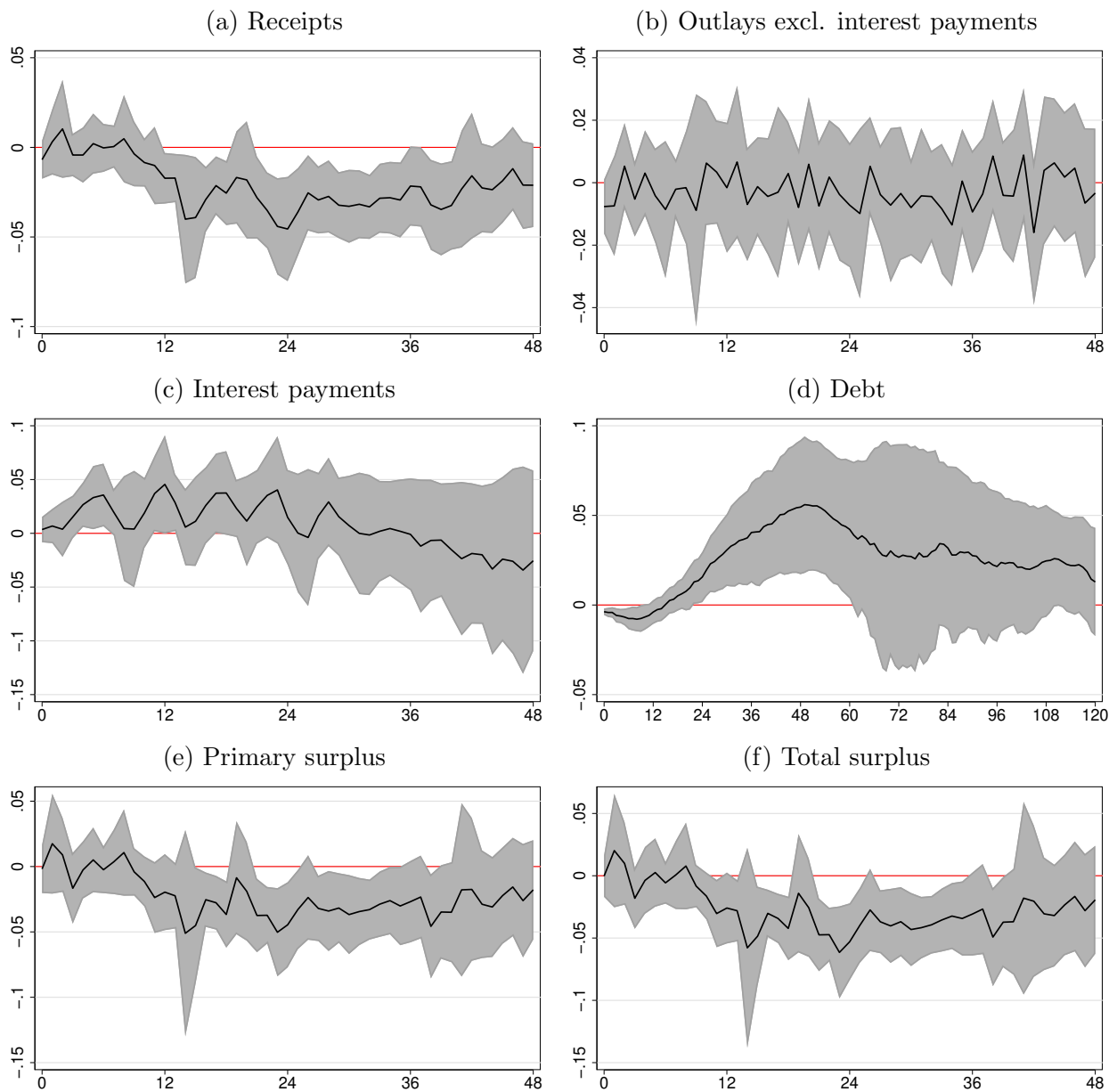
Note: response to a 100 basis point increase in the FFR target. The grey area is the 95% confidence interval with Driscoll-Kraay standard errors. Time is in months.

Figure 2 is context, figure 3 shows results. The response of receipts mimics that of output



with a slight lag: they fall by about 2-3% within two years, linger at that lower level for another year and revert in the fourth year. Outlays are flat: there is no counter-cyclical response of government expenditures. Interest payments increase with the FFR and revert back with the latter. Real debt builds up after a year and increases by about 4% after four years. Primary surplus and total surplus are flat: there is no counter-cyclical response of government expenditures.

Figure 3: Results



Note: response to a 100 basis point increase in the FFR target. The grey area is the 95% confidence interval with Driscoll-Kraay standard errors. Time is in months.

In the appendix,<sup>4</sup> I explore several variations on the baseline specification. First, I increase the number of lags without much consequence for the results (figure A.2). Second, I use plain-vanilla RR shocks which are constructed without fiscal forecasts (figure A.3).<sup>5</sup> Their inclusion in equation (1) turns out to be of little influence for the results: this is because, as Croushore and van Norden (2018) showed, the two shock series are highly correlated. The correlation coefficient of the standard RR shocks with those that I estimate is 0.96. Third, I redo the analysis with data for all government entities. Since I am not aware of systematic monthly data for state and local governments, the main analysis was restricted to the federal level. From a theoretical point of view, however, the behavior of non-federal entities is also interesting. At quarterly frequency, the NIPA tables and Flow of Funds provide time series for the general government sector. While the national accounts' accounting concepts are not directly comparable to those used in the *Treasury Bulletin*,<sup>6</sup> redoing the analysis with those series is a rough test of whether the findings are robust to including non-federal governments and using a different data source. As figure A.4 shows, and even though statistical significance is harder to achieve with quarterly data, the dynamics exhibited by general government series after a monetary shock are similar to those obtained for the federal government.

## 3.2 Interpretation

### 3.2.1 Output-Driven vs. Legislated Changes in Tax Receipts

There are three possible explanations for the response of receipts: (i) tax revenues fall with output for a given tax schedule, (ii) Congress systematically changes the tax schedule after monetary policy shocks, (iii) chance correlation. Numbers (i) and (ii), though they highlight different mechanisms, would be valid causal effects of monetary policy. Number (iii) is

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<sup>4</sup>See the first page of this article for a link to this appendix.

<sup>5</sup>I use the shock series updated by Coibion et al. (2017).

<sup>6</sup>In particular, the *Treasury Bulletin* considers government employee retirement funds as intra-governmental holdings, whereas they are part of the financial sector in the financial accounts (Federal Reserve Board, 2019).

worrisome in this context: the biggest RR monetary policy shocks occurred in the early Volcker era (Coibion, 2012); at about the same time, Ronald Reagan was presiding over one of the largest tax cuts in US history. Luckily, an informal piece of evidence suggests that the response of receipts is mostly due to number (i): on figure 3, the response of receipts follows that of output. Moreover, the fact that the fall in receipts dissipates after a few years doesn't seem consistent with a change in the tax schedule, which one would expect to last longer.

To investigate this question more formally, I use the database of *legislated* tax changes created by Romer and Romer (2010). They analyze the narrative record to quantify changes in the tax schedule, and classify them according to their underlying motivation. They thus distinguish four rationales that can drive a legislated tax change: finance extra spending, fight a recession, remedy an inherited deficit, and spur long-run growth. The first three categories may be endogenous to monetary policy.<sup>7</sup> The latter category is exogenous to monetary policy, but it is a first order of concern for it includes the Reagan tax cuts of 1981. In any case, my strategy to deal with these legislated changes is to add them as controls. If they are endogenous reactions to monetary policy, these are bad controls, no doubt. But whether these controls affect the results will indicate whether receipts fall because of legislated changes.

I estimate the following variation on equation (2):

$$y_{q+k} - y_{q-1} = \omega^k + \psi^k \hat{\epsilon}_q + X'_{q-1} \chi^k + \phi^k \left( z_{q-1}^{q+k} \right) + \xi_q^k \quad (4)$$

where  $y_q$  are receipts in quarter  $q$  and  $z_{q-1}^{q+k}$  is the accumulated legislated tax change between quarters  $q-1$  and  $q+k$  — the legislated tax changes database is quarterly so I switch to

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<sup>7</sup>Romer and Romer (2010) are interested in a different question — what are the effects of tax cuts on output. Hence their assessment of which tax changes are endogenous differs from mine. From their point of view, remedying an inherited deficit is exogenous since it is not driven by economic conditions. From my point of view, an inherited deficit can be the result of past monetary policy actions — the FOMC decides to generate less seigniorage for instance —, hence should be treated as potentially endogenous.

quarterly frequency for this exercise.<sup>8</sup> To measure legislated tax changes, I use the absolute amount of each tax change, retrieved by Romer and Romer (2010), divided by receipts collected in the year that preceded the tax change. I also experimented with expressing tax changes as a share of GDP, without a notable influence on the results.

The results (figure 4a) confirm the conclusion reached three paragraphs ago: legislated tax changes, be they exogenous or endogenous, do not explain the response of receipts. Adding exogenous tax changes as a control lessens the response of receipts in the third year but mostly preserves it.<sup>9</sup> This dispels the worry that the latter be driven by the coincidence of Volcker and Reagan shocks. Adding endogenous tax changes as a control has no bearing on the response of receipts. A final piece of evidence is given by figure 4b: once I add a year of lagged changes in industrial production as a control, the response of receipts is almost entirely gone. Again, industrial production is a bad control in so far as it responds to monetary policy. That its response, however, explains the response of receipts suggests monetary policy affects receipts *through* output.

### 3.2.2 Unresponsive outlays?

It is surprising that outlays (net of interest payments) be unresponsive to monetary shocks. One would expect, for instance, a counter-cyclical response of unemployment benefits after the monetary contraction triggers an increase in unemployment (figure 2d). The first explanation that comes to mind might be that “outlays” blend two concepts that are theoretically distinct: government purchases<sup>10</sup> and transfers. There is, unfortunately, no easy way to distinguish those in sources published by the Treasury. The NIPA tables, however, allow me to do so, at the cost of switching to quarterly data. But the results only thicken the puzzle (figure 4c): if anything, transfers decline after a monetary contraction — though that decline is not statistically significant for most quarters.<sup>11</sup>

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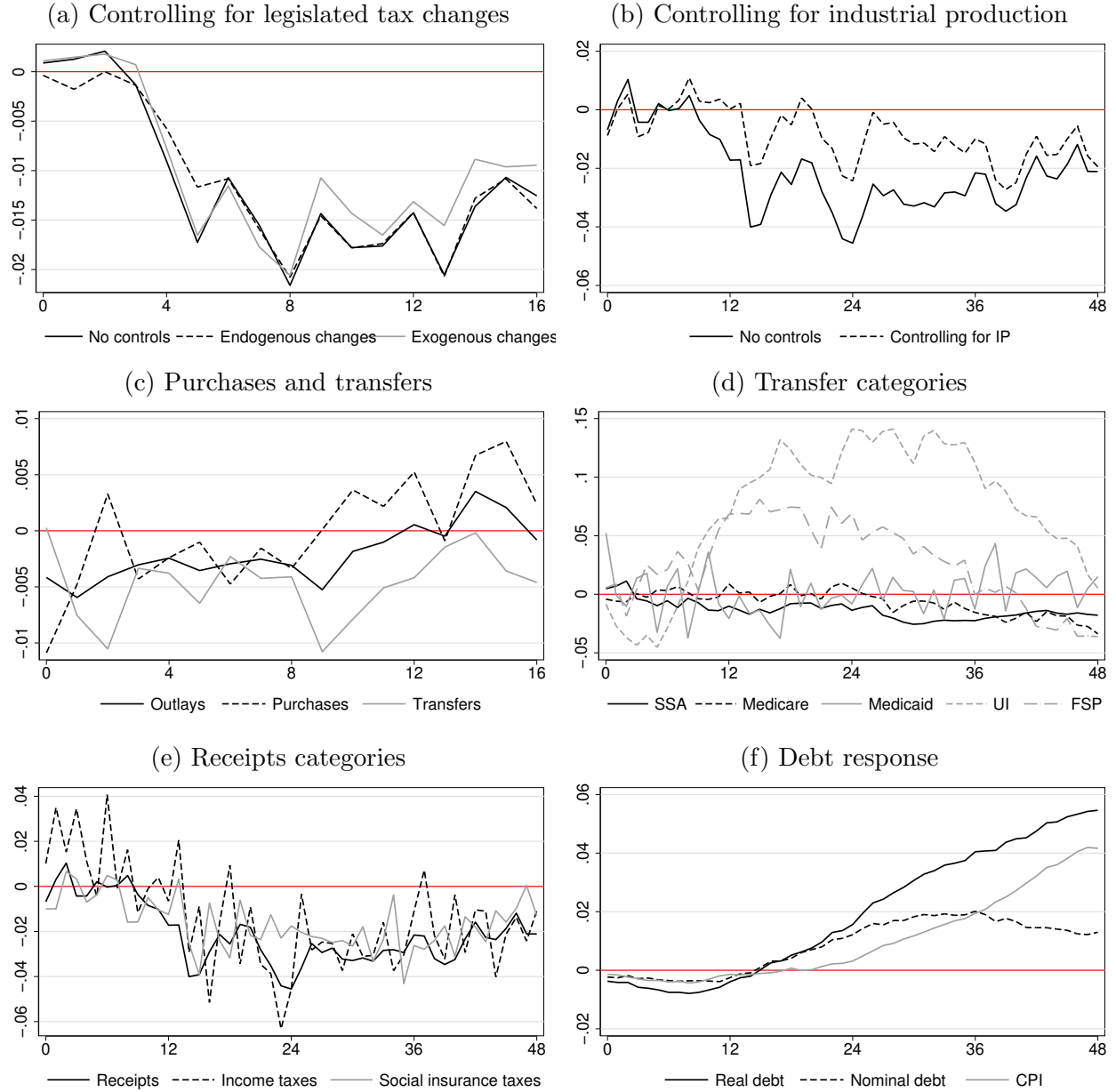
<sup>8</sup>I aggregate monthly receipts and shocks by summing them over quarters.

<sup>9</sup>See figure A.5 in the appendix for pictures with standard errors.

<sup>10</sup>See footnote 1.

<sup>11</sup>See figure A.6 in the appendix for pictures with standard errors.

Figure 4: Interpretation



Note: response to a 100 basis point increase in the FFR target. Lines are point estimates. Time is in quarters for figure 4a, in months otherwise. Abbreviations in the legend of figure 4d stand for: Social Security Administration (SSA), unemployment insurance (UI) and Food Stamp Program (FSP).

In fact, most of the transfers that are provided by the federal government should not be expected to be counter-cyclical. In 2007, the three biggest categories, which accounted for 70% of federal transfers, were Social Security, Medicare and Medicaid.<sup>12</sup> There is little reason to expect that old-age, disability and health insurance payments go up in a reces-

<sup>12</sup>In appendix table A.1, I break federal transfers down by category.

sion.<sup>13</sup> Programs such as unemployment insurance and food stamps are more likely to be counter-cyclical, but those two only amounted to 4% of the total. To investigate this more formally, I collected additional data from the *Monthly Treasury Statement* for these five types of transfers: Social Security, Medicare, Medicaid, unemployment insurance and food stamps.<sup>14</sup> Together, these accounted for 74% of federal transfers in 2007. Figure 4d confirms the speculation above: Social Security (SSA), Medicare and Medicaid exhibit no particular response to a monetary shock, while unemployment insurance (UI) does. So do food stamps (FSP), though to a lesser extent. UI's path closely follows that of the unemployment rate.<sup>15</sup>

This discussion implies that one's modeling choices for the response of transfers to monetary policy should depend on the details of the model itself. A model that does not feature unemployment, such as Kaplan et al.'s (2018), may have unresponsive transfers. A model that does, such as Gornemann et al.'s (2016), should not. Finally, that counter-cyclical transfers have a negligible influence on the budget constraint of the fiscal authority does not mean they have no macroeconomic effect. For example, McKay and Reis (2016) show that they can reduce the volatility of output through redistribution and social insurance.

### 3.2.3 Unpacking the Response of Receipts and Debt

Federal receipts incorporate many kinds of revenues: income, social security or excise taxes, customs duties, earnings by Federal Reserve Banks. In practice, most of receipts are income or social insurance taxes. In fiscal year 2007, they respectively accounted for 60 and 32% of receipts. Figure 4e shows that both categories react similarly.

The response of real debt can be driven by two mechanisms: an increase in nominal debt

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<sup>13</sup>Perhaps Medicaid payments, which go to low-income people, do, if there are more people eligible during a recession, or if those eligible tend to be sicker during that time. As we shall see, these mechanisms, if they are real, are not important enough to be detected by my impulse response functions.

<sup>14</sup>Social Security provides old-age and disability insurance, while Medicare offers health insurance to Americans aged 65 and older. I include the Supplemental Security Income Program in Social Security. Medicaid covers healthcare costs for people with low incomes. Food stamps are food-purchasing assistance to people with low incomes. The Food Stamp Program was renamed the Supplemental Nutrition Assistance Program (SNAP) in 2008. Since my sample ends in 2007, I use the old terminology.

<sup>15</sup>Again, figure A.6 in the appendix features pictures with standard errors.

or a fall in its deflator. I plot the response of real debt, nominal debt and the deflator on figure 4f. It turns out these two mechanisms contribute to the buildup in real debt but the bulk of the response is accounted for by the fall in the deflator.

## 4 A Minimalist Framework

I now show that a parsimonious model fits the data well. The main ingredients of the model are: long-term debt, a tax on output and passive government expenditures.

### 4.1 Environment

Consider the theoretical equivalent of equation (3):

$$D_t - D_{t-1} = G_t + INT_t - T_t \quad (5)$$

where  $D_t$  is the amount of debt at time  $t$  and carried into period  $t + 1$ ,  $G_t$  government expenditures — outlays excluding interest payments —,  $INT_t$  interest payments and  $T_t$  tax receipts. All variables are in nominal terms.

A model with one-period debt would be hopeless in fitting the response of interest payments. Indeed, in such a model real interest payments are given by:

$$\frac{INT_t}{P_t} = i_{t-1} \frac{D_{t-1}}{P_{t-1}} \frac{P_{t-1}}{P_t} \quad (6)$$

where  $i_{t-1}$  is the interest rate from  $t - 1$  to  $t$ . Since real debt and inflation are roughly constant in the short run, interest payments would increase in proportion to the interest rate. Assuming a steady state nominal interest rate of 6% — the average over the sample —, interest payments would increase by 17% within a month after a 100 basis point hike in  $i_t$ . Figure 3 shows that this is strongly rejected by the data.

To introduce long-term debt in a tractable way, I assume that the government issues

debt with a geometric maturity structure, in the form of zero-coupon bonds. At time  $t_0$ , the government issues  $D_{t_0}^n$  in new debt. Of the debt issued at time  $t_0$ , it pays back, at time  $t_0 + 1$ ,  $(1 - \rho)D_{t_0}^n$  in principal and  $i_{t_0, t_0+1} \times (1 - \rho)D_{t_0}^n$  in interest, where  $i_{t_0, t_0+1}$  is the interest rate from  $t_0$  to  $t_0 + 1$ . It does not pay interest on debt that matures later since all debt is in the form of zero-coupon bonds. At time  $t_0 + 2$ , it pays back  $\rho(1 - \rho)D_{t_0}^n$  in principal and  $i_{t_0, t_0+2} \times \rho(1 - \rho)D_{t_0}^n$  in interest. And so on. Thus, the amount of debt issued at time  $t_0$  and due at time  $t$  equals  $\rho^{t-t_0-1}(1 - \rho)D_{t_0}^n$ , which pays interest rate  $i_{t_0, t}$ .  $\rho$  governs the maturity of the debt.  $\rho = 0$  is the one-period case.  $\rho = 1$  means that debt is never paid back.

As a result, total interest payments at time  $t$  are the sum of interest payments on debt issued in all previous periods and maturing at time  $t$ :

$$INT_t = (1 - \rho) \sum_{t_0=-\infty}^{t-1} \rho^{t-t_0-1} i_{t_0, t} D_{t_0}^n$$

Provided the expectation hypothesis holds,  $i_{t_0, t}$  is:

$$i_{t_0, t} = E_{t_0} \Pi_{s=0}^{t-t_0-1} (1 + i_{t_0+s}) - 1$$

Log-linearizing around a steady state where real variables are constant and the inflation rate is  $\pi^*$ :

$$\begin{aligned} \hat{int}_t = \kappa \sum_{t_0=-\infty}^{t-1} \left( \frac{\rho}{1 + \pi^*} \right)^{t-t_0-1} & \left[ (1 + i^*)^{t-t_0-1} \sum_{s=0}^{t-t_0-1} E_{t_0} \hat{i}_{t_0+s} \right. \\ & \left. + ((1 + i^*)^{t-t_0} - 1) (\hat{d}_{t_0}^n - \hat{\pi}_{t_0, t}) \right] \end{aligned} \quad (7)$$

where:

$$\kappa \equiv \frac{(1 + \pi^* - \rho)(1 + \pi^* - \rho(1 + i^*))}{i^*(1 + \pi^*)^2}$$

Lower-case letters ( $int_t$ ,  $d_t^n$ ) denote the log of real variables and hats deviations from steady



state.  $\hat{\pi}_{t_0,t}$  is inflation from  $t_0$  to  $t$ , in deviation from steady state.  $\hat{i}_t$  is the deviation from steady state of the nominal interest rate. If all debt is one-period ( $\rho = 0$ ), equation (7) collapses to:

$$\hat{i}nt_t = \frac{\hat{i}_{t-1}}{i^*} + \hat{d}_{t-1} - \hat{\pi}_t \quad (7')$$

Which is just the log-linear version of equation (6). As  $\rho$  grows, interest payments react more slowly to a change in the interest rate since debt must be rolled-over before the new interest rate is paid.

The response of debt over time is given by the log-linearized budget constraint:

$$\hat{d}_t - \frac{1}{1 + \pi^*} (\hat{d}_{t-1} - \hat{\pi}_t) = \frac{g^*}{d^*} \hat{g}_t + \frac{(1 - \rho)i^*}{1 + \pi^* - \rho(1 + i^*)} \hat{i}nt_t - \frac{t^*}{d^*} \hat{t}_t \quad (8)$$

supplemented with the law of motion of debt:

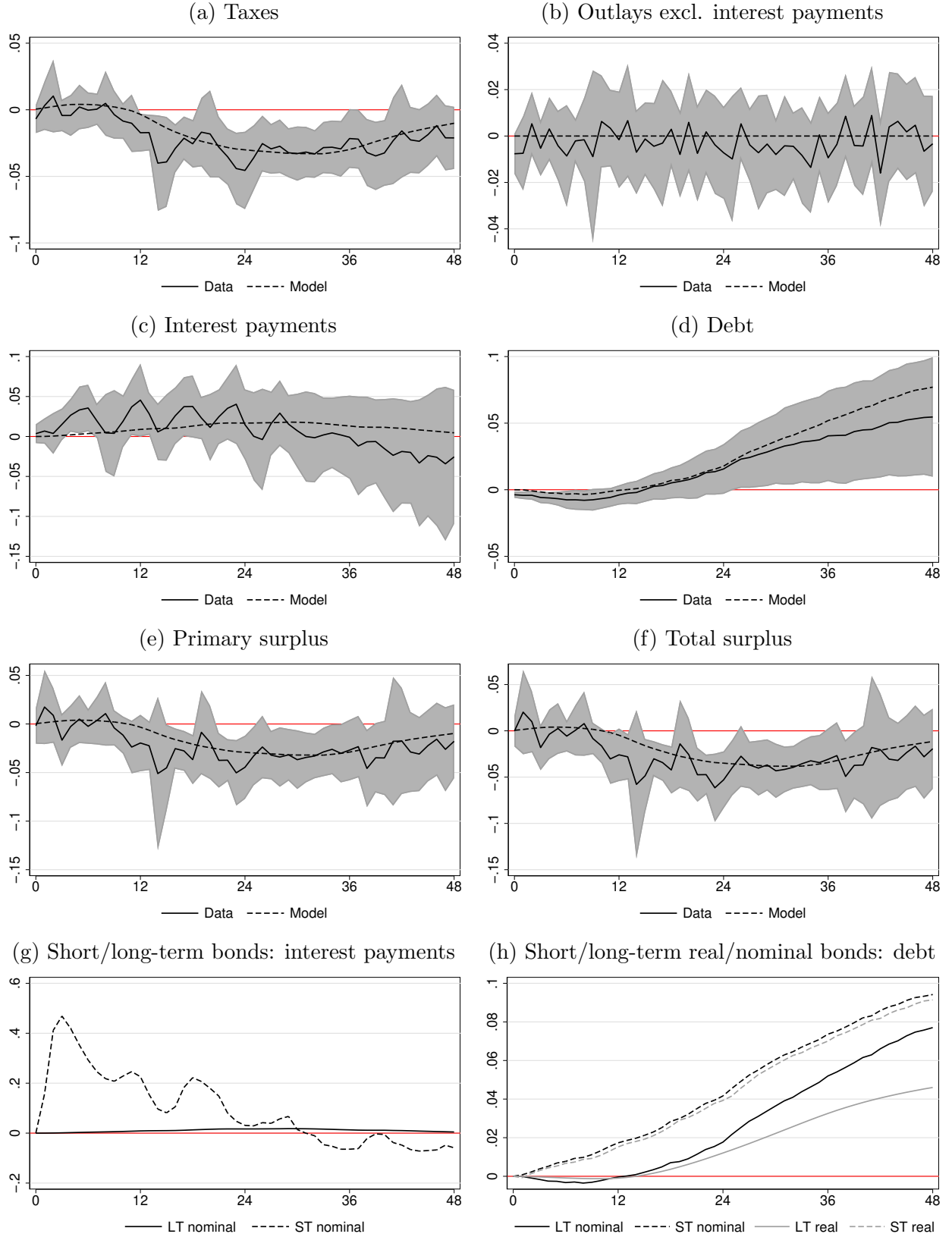
$$\hat{d}_t = \left(1 - \frac{\rho}{1 + \pi^*}\right) \hat{d}_t^n + \frac{\rho}{1 + \pi^*} (\hat{d}_{t-1} - \hat{\pi}_t) \quad (9)$$

Finally, I make two assumptions on the behavior of the fiscal authority that are suggested by the empirical results of the previous section. To reflect the tendency of receipts to lag the response of output, taxes are a function of the past year's output:  $T_t/P_t = \bar{T}(\frac{1}{12} \sum_{s=0}^{11} y_{t-s})$ . Moreover, government expenditures are constant:  $G_t/P_t = g^*$ . In real log-linear terms these two equations become:

$$\hat{t}_t = \frac{\tau}{12} \sum_{s=0}^{11} \hat{y}_{t-s}, \quad \tau = \frac{\bar{T}'(y^*)}{\bar{T}(y^*)} \quad (10)$$

$$\hat{g}_t = 0 \quad (11)$$

Figure 5: Theoretical results



Note: figures 5a to 5f compare actual impulse response functions to those generated by the model. The solid line is the point estimate, the grey area the 95% confidence interval, the dashed line the prediction of the model. Figures 5g and 5h compare those predictions under different assumptions for government debt: ST and LT stand for short ( $\rho = 0$ ) and long term ( $\rho > 0$ ). Time is in months.

## 4.2 Calibration

Equations (7) to (11) describe the response of  $\hat{t}$ ,  $\hat{g}$ ,  $\hat{int}$  and  $\hat{d}$  for given paths of  $\hat{y}$ ,  $\hat{\pi}$  and  $\hat{i}$ . I feed the point estimate for the response of the latter three variables into the model, and simulate that of the former four. This exercise requires five parameters to be calibrated: the ratios of tax and outlays to debt ( $t^*/d^*$  and  $g^*/d^*$ ), the steady state interest and inflation rates ( $i^*$  and  $\pi^*$ ), the rate of persistence of debt ( $\rho$ ) and the elasticity of taxes with respect to output ( $\tau$ ). I make  $g^*/d^*$ ,  $i^*$  and  $\pi^*$  equal to their mean over the sample, and pick  $t^*/d^*$  to clear the budget constraint in steady state. I set  $\rho$  to give a weighted average maturity of debt of 45 months, which is in line with actual data in the 1980s,<sup>16</sup> and  $\tau$  to minimize the distance between the simulated and estimated responses of tax receipts. This procedure yields  $\tau = 1.41$ .<sup>17</sup>

I display the results in figure 5. The model fits the data well. Note that, apart from taxes, I used none of the impulse response functions to calibrate parameters. Interest payments exhibit the hump-shaped response of the data: after the interest rate hike, they increase sluggishly as debt is rolled-over. After about 20 months, the interest rate reverts to 0 and interest payments start declining. Debt accumulates as the budget balance swings into deficit.

To illustrate the importance of long-term debt, I run a simple experiment in my model: feeding in the same path for  $\hat{y}$ ,  $\hat{\pi}$  and  $\hat{i}$ , what happens if all debt is one period? As expected, the response of interest payments is radically different (figure 5g). It looks exactly like the response of the FFR... up to one detail: the magnitude is scaled by  $1/i^*$  as equation (7') suggests. This translates into a stronger response of debt: over the simulated horizon, it is up to 2% higher when debt is short term.

Long-term debt introduces another complication: it matters whether bonds are labeled in nominal or real terms. Indeed, the real value of long-term nominal bonds is exposed to

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<sup>16</sup>See Treasury Department - Office of Debt Management (2018, p. 23).

<sup>17</sup>Table A.2 in the appendix summarizes these calibration choices.

unexpected changes in the price level. As a result, debt relative to the price level builds up as the latter falls. When bonds are labeled in real terms, the government is hedged against that risk, and real debt increases much less (figure 5h).<sup>18</sup> This distinction is almost irrelevant with short-term bonds as the price level does not move much on impact.

## 5 Conclusion: Takeaways for HANK Models

Kaplan et al. (2018, pp. 732-34) discuss several possible adjustments to a monetary shock: the government can change transfers, expenditures, tax rates, or let real debt adjust to clear its budget constraint. Judging by my estimates, the latter case is the empirically relevant one. Incidentally, it is also the case that implies the smallest effects of monetary policy as other cases entail changes that amplify the response of output — a decrease in transfers or expenditures, or an increase in tax rates following a contractionary shock.

Another modeling detail might shape the response of the economy to monetary policy: the maturity of government debt. As a matter of fact, Kaplan et al. cite interest payments as the primary reason why monetary policy affects the government’s budget constraint. Since their government issues bonds with infinitesimal maturity — they’re working in continuous time —, interest payments must react in proportion to the interest rate. In reality, interest payments react only moderately to monetary shocks. In contemporaneous work, Auclert et al. (2020) introduce long-term debt in a HANK model with sticky household expectations, and indeed find the fiscal response to be less important. Their model, however, may be going too far in that direction: the government issues real bonds, which mutes the debt-deflation channel, and downplays the size of the required adjustment. In reality, most government debt is nominal.<sup>19</sup> I leave a formal analysis of these issues to future research.

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<sup>18</sup>See appendix section C for the equations with real bonds.

<sup>19</sup>At the end of 2007, Treasury inflation-protected securities (TIPS) represented 9% of federal debt held by the public (*Treasury Bulletin*). This proportion is even lower today (7% in December 2020), and it was 0 until TIPS were introduced in 1997.

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