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ABSTRACT

The textbook optimal policy response to an increase in government debt is simple—monetary policy should actively target inflation, and fiscal policy should smooth taxes while ensuring debt sustainability. Such policy prescriptions presuppose an ability to commit. Without that ability, the temptation to use inflation surprises to offset monopoly and tax distortions, as well as to reduce the real value of government debt, creates a state-dependent inflationary bias problem. High debt levels and short-term debt exacerbate the inflation bias. But this produces a debt stabilization bias because the policy maker wishes to deviate from the tax smoothing policies typically pursued under commitment, by returning government debt to steady-state. As a result, the response to shocks in New Keynesian models can be radically different, particularly when government debt levels are high.

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Optimal Time-Consistent Monetary, Fiscal and Debt Maturity Policy

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1 Introduction

Conventional monetary-fiscal policy analysis assigns monetary policy the task of controlling demand and inflation and fiscal policy the job of ensuring fiscal sustainability. Optimal policy analyses support this policy assignment. In sticky price New Keynesian models with one-period government debt, Schmitt-Grohe and Uribe (2004b) show that even a mild degree of price stickiness implies negligible use of inflation surprises to stabilize debt and near random walk behavior in government debt and tax rates when policy makers can commit to time-inconsistent monetary and fiscal policies, in response to shocks. In other words, monetary policy should be used to stabilize inflation, not debt, while a tax smoothing fiscal policy ensures fiscal sustainability.[1]

Despite this apparent consensus on broad features of a desirable policy mix, empirical evidence suggests that policy makers, even in recent years, often do not behave in this way (see Bianchi and Ilut (2017) and Chen et al. (2018) for the United States). And the ability of policy makers to commit, which is implicit in the consensus policy assignment, is also doubtful. This paper studies jointly optimal monetary and fiscal policy when policy makers cannot commit. We augment a standard New Keynesian model with optimally chosen distortionary taxation and government spending, as well as government debt issued with a realistic maturity structure. The policy maker may operate with a mild degree of myopia. Myopia serves as a proxy for the political frictions in policy making that lead the policy maker to give more weight to the short-run costs of fiscal consolidation than to the longer-term gains of lower debt.[2] We solve the non-linear model using global solution methods. The

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[1]Although Sims (2013) questions the robustness of this result when government can issue long-term nominal bonds since this implies variations in bond prices can be used as a device to stabilize debt, Leeper and Leith (2017) find that, as part of a Ramsey problem, the consensus policy assignment remains largely optimal.

[2]See Alesina and Passalacqua (2017) for a recent survey of the political economy of government debt.

equilibrium produces a plausible steady-state and, by allowing for switches in the degree of policy maker myopia, captures the major trends in the American debt-to-GDP ratio that Figure 1 depicts.

Four key findings emerge:

1. A trade-off between the costs of inflation and the desire to generate surprise inflation drives the equilibrium. That trade-off varies with the level and the maturity of government debt. The policy maker faces a temptation to use inflation surprises to offset inefficiencies that arise from monopolistic competition and distortionary taxation. There is an additional temptation to use inflation surprises to influence the real value of outstanding government debt—a temptation that grows with the level of debt and shrinks with the average maturity of that debt. This state-dependent inflation bias induces the policy maker to return debt to steady state, which the Ramsey policy maker would not do, to create a costly debt-stabilization bias.

2. Changes in how myopically the policy maker behaves allow the model to capture key fiscal trends in the figure. The post-war reduction in debt-to-GDP stems from higher taxes and an increase in inflation that the debt-dependent inflationary bias creates. Conversely, increases in debt—as in the 1980s—arise from significant tax cuts and a sharp reduction in inflation when a relatively myopic policy maker discounts the implications of rising debt levels. This is a new interpretation of the Volcker disinflation. In the long run, though, the patient policy maker who achieves a lower debt-to-GDP ratio will enjoy lower tax rates and inflation than a myopic policy maker who chooses to sustain a higher debt-to-GDP ratio.

3. The state-dependent inflation bias implies that the optimal time-consistent policy response to shocks depends on debt levels. A relatively myopic policy maker sustains higher debt and inflation in the long-run. In such a state, the policy maker's response to cost-push shocks largely reflects a desire to mitigate the fiscal repercussions of the shock. Mark-up shocks are more inflationary in a New Keynesian model augmented with fiscal policy and government debt.

4. Unlike the case of commitment, allowing the policy maker to choose the relative proportions of short- versus long-term debt as part of the time-consistent policy problem does not result in the policy maker constructing an extreme portfolio where a large stock of short-term assets is funded by issuing long-term debt in order to benefit from shifts in the yield curve in the face of shocks (see Debortoli et al. (2017) and the discussion in Leeper and Leith (2017)). Instead, the policy maker issues a small amount of short-term debt alongside long-term debt which they vary to influence the policy mix. For example, during a period of fiscal consolidation, increasing the proportion of short-term debt leads to a relaxtion of monetary policy ceteris paribus, which supports a slower rate of debt reduction.

These results touch upon a number of literatures, which appendix A discusses. The paper proceeds as follows. The benchmark model is described in section 2 and the optimal time consistent policy problem in section 3. Section 4, describes the solution method and 5 presents the numerical results. Section 6 concludes.

2 The Model

The model is a standard New Keynesian model, but augmented to include the government's budget constraint where government spending is financed by distortionary taxation and/or long-term borrowing.[3]

2.1 Households

The utility function of the representative household takes the specific form

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} + \chi \frac{G_t^{1-\sigma_g}}{1-\sigma_g} - \frac{N_t{}^{1+\varphi}}{1+\varphi} \right) \tag{1}$$

Households appreciate private consumption, C_t, as well as the provision of public goods, G_t, and dislike supplying labor, N_t. Private consumption is made up of a basket of goods defined by,

$$C_t \equiv \left(\int_0^1 C_t(j)^{\frac{\epsilon_t - 1}{\epsilon_t}} dj \right)^{\frac{\epsilon_t}{\epsilon_t - 1}} \tag{2}$$

where j denotes the good's variety and $\epsilon_t > 1$ is the elasticity of substitution between varieties. This is assumed to be time-varying, following the AR(1) process,

$$\ln(\epsilon_t) = (1 - \rho_\epsilon) \ln(\bar{\epsilon}) + \rho_\epsilon \ln(\epsilon_{t-1}) + \sigma_\epsilon \varepsilon_t, \varepsilon_t \sim N(0,1) \tag{3}$$

as a device for introducing mark-up shocks.

The households' optimal allocation of consumption across individual goods implies their demand for good j,

$$C_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon_t} C_t$$

where $P_t(j)$ is the price of good j and the aggregate price level is defined as, $P_t \equiv \left(\int_0^1 P_t(j)^{1-\epsilon_t} dj \right)^{\frac{1}{1-\epsilon_t}}$.

The budget constraint at time t is given by

$$P_t^M B_t^M \leq \Xi_t + (1 + \rho P_t^M) B_{t-1}^M + W_t N_t (1 - \tau_t) - P_t C_t + Tr_t \tag{4}$$

where $\int_0^1 P_t(j) C_t(j) dj = P_t C_t$, Ξ_t is the representative household's share of profits in the imperfectly competitive firms producing these goods, W_t are wages, and τ_t is an wage income tax rate. There is also an exogenous fiscal transfer to the household, $Tr_t = P_t tr$, which is introduced to ensure the model reflects the data in terms of the breakdown of fiscal expenditures into public consumption and transfers.[4] In period t households buy government

[3] Most countries issue long-term nominal debt such that even modest changes in inflation and interest rates can have substantial impact on the market value of debt - see Hall and Sargent (2011) and Sims (2013) for the empirical findings on the contribution of this kind of fiscal financing to the decline in the U.S. debt-GDP ratio from 1945 to 1974.

[4] It is important to note that real transfers are an exogenously given constant and are not considered to be a policy instrument. Allowing transfers to be chosen optimally would enable the policy maker to levy a lump-sum tax in order to finance a negative distortionary labor income tax and offset the distortion arising from monopolistic competition,. This is a typical, but unrealistic, assumption in linear-quadratic analyses of optimal fiscal and monetary policy in New Keynesian models.

bonds, B_t^M, at price P_t^M, which, following Woodford (2001), are actually a portfolio of many bonds which pay a declining coupon of ρ^j dollars $j+1$ periods after they were issued, where $0 < \rho \leq \beta^{-1}$. A measure of the duration of the bond is given by $(1-\beta\rho)^{-1}$, which allows calibration of ρ to capture the observed maturity structure of government debt.[5] Households bring nominal wealth of $(1+\rho P_t^M)B_{t-1}^M$ into period t.

Households maximize utility subject to the budget constraint (4) to obtain the optimal allocation of consumption across time and price the declining payoff consols,

$$\beta E_t \left\{ \left(\frac{C_t}{C_{t+1}} \right)^{\sigma} \left(\frac{P_t}{P_{t+1}} \right) (1+\rho P_{t+1}^M) \right\} = P_t^M \tag{5}$$

It is convenient to define the stochastic discount factor (for nominal payoffs) for later use, $Q_{t,t+1} \equiv \beta \left(\frac{C_t}{C_{t+1}} \right)^{\sigma} \left(\frac{P_t}{P_{t+1}} \right)$where $E_t Q_{t,t+1} = R_t^{-1}$ is the inverse the short-term interest rate which is the policy instrument of the monetary authority.

The second first order condition (FOC) relates to their labor supply decision and is given by,

$$(1-\tau_t) \left(\frac{W_t}{P_t} \right) = N_t^{\varphi} C_t^{\sigma} \tag{6}$$

That is, the marginal rate of substitution between consumption and leisure equals the after-tax wage rate.

Besides these FOCs, necessary and sufficient conditions for household optimization also require the households' budget constraints to bind with equality. Defining $D_t \equiv (1 + \rho P_t^M)B_{t-1}^M$, the no-Ponzi-game condition can be written as,

$$\lim_{T \to \infty} E_t \left[\frac{1}{R_{t,T}} \frac{D_T}{P_T} \right] \geq 0 \tag{7}$$

where $R_{t,T} \equiv \prod_{s=t}^{T-1} \left(\frac{1+\rho P_{s+1}^M}{P_s^M} \frac{P_s}{P_{s+1}} \right)$ for $T \geq 1$ and $R_{t,t} \equiv 1$.

2.2 Government

Aggregate public consumption takes the same form as private consumption,[6]

$$G_t = \left(\int_0^1 G_t(j)^{\frac{\epsilon_t - 1}{\epsilon_t}} dj \right)^{\frac{\epsilon_t}{\epsilon_t - 1}} \tag{8}$$

such that government demand for individual goods is given by,

$$G_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\epsilon_t} G_t$$

[5]In the special case where $\rho = 0$, the bonds reduce to the familiar single period bonds typically studied in the literature.

[6]An alternative modeling approach would be to introduce an 'aggregator' firm which converts the individual goods to a final output which is purchased by households and the government. The model implies, equivalently, that households and the government perform this aggregation themselves.

Government expenditures, consisting of transfers, Tr_t, and consumption, G_t, are financed by levying labor income taxes at the rate τ_t, and by issuing long-term bonds B_t^M. The government's sequential budget constraint is then given, in real terms, by

$$P_t^M b_t = (1+\rho P_t^M)\frac{b_{t-1}}{\Pi_t} - w_t N_t \tau_t + G_t + tr \tag{9}$$

where real debt is defined as, $b_t \equiv B_t^M/P_t$, and real wages, $w_t \equiv W_t/P_t$. Transfers $tr = Tr_t/P_t$ are fixed at a data-consistent average. Fiscal policy instruments are tax rates, τ_t and government consumption, G_t.

2.3 Firms

Firm j faces three constraints, firstly a linear production function,

$$Y_t(j) = N_t(j) \tag{10}$$

where the real marginal cost of production is defined as $mc_t \equiv W_t/P_t = (1-\tau_t)N_t^{\varphi}C_t^{\sigma}$. Secondly, a demand curve for their product,

$$Y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\epsilon_t} Y_t$$

which is the sum of private and public demand, where $Y_t = \left[\int_0^1 Y_t(j)^{\frac{\epsilon_t - 1}{\epsilon_t}} dj\right]^{\frac{\epsilon_t}{\epsilon_t - 1}}$. Finally, quadratic adjustment costs in changing prices, as in Rotemberg (1982), defined for firm j as,

$$\eta_t(j) \equiv \frac{\phi}{2}\left(\frac{P_t(j)}{P_{t-1}(j)} - 1\right)^2 Y_t \tag{11}$$

where $\phi \geq 0$ measures the degree of nominal price rigidity. The adjustment cost, which accounts for the negative effects of price changes on the customer–firm relationship, increases in magnitude with the size of the price change and with the overall scale of economic activity Y_t.

The problem facing firm j is to maximize the discounted value of nominal profits,

$$\max_{P_t(j)} E_t \sum_{z=0}^{\infty} Q_{t,t+z}\Xi_{t+z}(j)$$

subject to these constraints above, where nominal profits are defined as,

$$\Xi_t(j) \equiv P_t(j)Y_t(j) - mc_t Y_t(j) P_t - \frac{\phi}{2}\left(\frac{P_t(j)}{P_{t-1}(j)} - 1\right)^2 P_t Y_t$$

The FOCs imply the following non-linear Phillips curve relationship,

$$\Pi_t(\Pi_t - 1) = \beta E_t\left[\left(\frac{C_t}{C_{t+1}}\right)^{\sigma}\frac{Y_{t+1}}{Y_t}\Pi_{t+1}(\Pi_{t+1}-1)\right] + \phi^{-1}((1-\epsilon_t) + \epsilon_t mc_t) \tag{12}$$

where $\Pi_t \equiv P_t/P_{t-1}$ is the gross rate of inflation.

2.3.1 Market Clearing

Goods market clearing requires, for each good j,

$$Y_t(j) = C_t(j) + G_t(j) + \eta_t(j)$$

such that, in a symmetrical equilibrium,

$$Y_t\left[1 - \frac{\phi}{2}\left(\Pi_t - 1\right)^2\right] = C_t + G_t \tag{13}$$

There is also market clearing in the bonds market where the portfolio of long-term bonds held by households evolves according to the government's budget constraint.

That completes the description of the model. Before analyzing the optimal policy problem the competitive equilibrium is defined as follows.

Definition 1 (Competitive equilibrium)**.** *A competitive equilibrium consists of government policies,* $\left\{R_t, G_t, \tau_t, b_t^M\right\}_{t=0}^{\infty}$*, prices,*$\left\{w_t, P_t^M\right\}_{t=0}^{\infty}$*, and private sector allocations,* $\{C_t, N_t, Y_t, \Xi_t, \Pi_t\}_{t=0}^{\infty}$*, satisfying* $\forall \{\epsilon_t\}_{t=0}^{\infty}$*, (i) the private sector optimization taking government policies and prices as given, that is, the household budget constraint (4), the production function* $Y_t = N_t$*, and the optimality conditions, (5), (6) and (12); (ii) the market clearing condition (13); (iii) the government's budget constraint (9); and (iv) the no-Ponzi-game condition (7), for a given initial level of government debt* b_{-1}*.*

3 Optimal Policy Under Discretion

The policy under discretion seeks to maximize the value function,

$$V(b_{t-1}, \epsilon_t) = \max\left\{\frac{C_t^{1-\sigma}}{1-\sigma} + \chi\frac{G_t^{1-\sigma_g}}{1-\sigma_g} - \frac{(Y_t)^{1+\varphi}}{1+\varphi} + \widetilde{\beta}E_t\left[V(b_t, \epsilon_{t+1})\right]\right\}$$

subject to the resource constraint (13), the New Keynesian Phillips curve (12), and the government's budget constraint,(9). The possibility that the policy maker suffers from a degree of myopia is captured by assuming they may discount the future more heavily than households, $\widetilde{\beta} \leq \beta$.

In conducting this optimization the policy maker is constrained to act in a time-consistent manner. In other words the policy maker cannot make time-inconsistent promises as to how they will behave in the future in order to have a beneficial impact on current policy trade-offs through expectations as they would under Ramsey policy. Instead, they take expectations as given except to the extent that the debt stock they bequeath to the future affects time-consistent policy choices in the future. To capture this future expectations are replaced by the following state-dependent auxiliary functions,

$$M(b_t, \epsilon_{t+1}) \equiv (C_{t+1})^{-\sigma} Y_{t+1}\Pi_{t+1}\left(\Pi_{t+1} - 1\right) \tag{14}$$

$$L(b_t, \epsilon_{t+1}) \equiv (C_{t+1})^{-\sigma}(\Pi_{t+1})^{-1}(1 + \rho P_{t+1}^M) \tag{15}$$

$$
\begin{array}{ll}
C_t & \begin{array}{c} C_t^{-\sigma} - \lambda_{1t} + \lambda_{2t}\left[\sigma\epsilon_t(1-\tau_t)^{-1}Y_t^{\varphi}C_t^{\sigma-1} + \sigma\phi\beta C_t^{\sigma-1}Y_t^{-1}E_t\left[M(b_t,\epsilon_{t+1})\right]\right] \\ +\lambda_{3t}\left[\sigma\beta b_t C_t^{\sigma-1}E_t\left[L(b_t,\epsilon_{t+1})\right] - \rho\sigma\beta\frac{b_{t-1}}{\Pi_t}C_t^{\sigma-1}E_t\left[L(b_t,\epsilon_{t+1})\right] + \sigma\left(\frac{\tau_t}{1-\tau_t}\right)(Y_t)^{1+\varphi}C_t^{\sigma-1}\right] = 0 \end{array} \\
Y_t & \begin{array}{c} -Y_t^{\varphi} + \lambda_{1t}\left[1-\frac{\phi}{2}(\Pi_t-1)^2\right] + \lambda_{3t}\left[(1+\varphi)Y_t^{\varphi}C_t^{\sigma}\left(\frac{\tau_t}{1-\tau_t}\right)\right] \\ +\lambda_{2t}\left[\epsilon_t\varphi(1-\tau_t)^{-1}Y_t^{\varphi-1}C_t^{\sigma} - \phi\beta C_t^{\sigma}Y_t^{-2}E_t\left[M(b_t,\epsilon_{t+1})\right]\right] = 0 \end{array} \\
\tau_t & \epsilon_t\lambda_{2t} + \lambda_{3t}Y_t = 0 \\
G_t & \chi G_t^{-\sigma_g} - \lambda_{1t} - \lambda_{3t} = 0 \\
\Pi_t & -\lambda_{1t}\left[Y_t\phi(\Pi_t-1)\right] - \lambda_{2t}\left[\phi(2\Pi_t-1)\right] + \lambda_{3t}\left[\frac{b_{t-1}}{\Pi_t^2}\left(1+\rho\beta C_t^{\sigma}E_t\left[L(b_t,\epsilon_{t+1})\right]\right)\right] = 0 \\
b_t & \begin{array}{c} -\widetilde{\beta}E_t\left[\lambda_{3t+1}\frac{1}{\Pi_{t+1}}(1+\rho P_{t+1}^M)\right] + \lambda_{2t}\left[\phi\beta C_t^{\sigma}Y_t^{-1}E_t\left[M_1(b_t,\epsilon_{t+1})\right]\right] \\ +\beta\lambda_{3t}\left[C_t^{\sigma}E_t\left[L(b_t,\epsilon_{t+1})\right] + b_tC_t^{\sigma}E_t\left[L_1(b_t,\epsilon_{t+1})\right] - \rho\frac{b_{t-1}}{\Pi_t}C_t^{\sigma}E_t\left[L_1(b_t,\epsilon_{t+1})\right]\right] = 0 \end{array}
\end{array}
$$

and the Lagrangian for the policy problem can be written as,

$$
\begin{aligned}
\mathcal{L} = & \left\{\frac{C_t^{1-\sigma}}{1-\sigma} + \chi\frac{G_t^{1-\sigma_g}}{1-\sigma_g} - \frac{(Y_t)^{1+\varphi}}{1+\varphi} + \widetilde{\beta}E_t[V(b_t,\epsilon_{t+1})]\right\} \\
& + \lambda_{1t}\left[Y_t\left(1-\frac{\phi}{2}(\Pi_t-1)^2\right) - C_t - G_t\right] \\
& + \lambda_{2t}\left[\begin{array}{c} (1-\epsilon_t) + \epsilon_t(1-\tau_t)^{-1}Y_t^{\varphi}C_t^{\sigma} - \phi\Pi_t(\Pi_t-1) \\ +\phi\beta C_t^{\sigma}Y_t^{-1}E_t\left[M(b_t,\epsilon_{t+1})\right] \end{array}\right] \\
& + \lambda_{3t}\left[\begin{array}{c} \beta b_tC_t^{\sigma}E_t\left[L(b_t,\epsilon_{t+1})\right] - \frac{b_{t-1}}{\Pi_t}\left(1+\rho\beta C_t^{\sigma}E_t\left[L(b_t,\epsilon_{t+1})\right]\right) \\ +\left(\frac{\tau_t}{1-\tau_t}\right)(Y_t)^{1+\varphi}C_t^{\sigma} - G_t - tr \end{array}\right]
\end{aligned}
\tag{16}
$$

where the model equilibrium also requires us to define bond prices, $P_t^M = \beta C_t^{\sigma}E_t\left[L(b_t,\epsilon_{t+1})\right]$ since these are embedded in the auxiliary function $L(b_t,\epsilon_{t+1})$. The policy maker optimizes (16) by choosing $C_t, G_t, Y_t, \Pi_t, \tau_t, b_t$ and the multipliers, λ_{1t}, λ_{2t}, λ_{3t}. It should be noted that even though the policy maker optimizes with respect to all endogenous variables, they are not acting as a social planner. Instead, they are choosing standard policy instruments in order to influence the decentralized equilibrium in a manner which maximizes their objective function subject to the time-consistency constraint. The FOCs for the policy problem are detailed below.

The discretionary equilibrium is determined by the system given by the FOCs, the constraints in (16), the auxiliary equations, (14) and (15), bond prices, $P_t^M = \beta C_t^{\sigma}E_t\left[L(b_t,\epsilon_{t+1})\right]$, and finally the exogenous process for the markup shock, (3). The solution to this system is a set of time-invariant Markov-perfect equilibrium policy rules $y_t = H(s_{t-1})$ mapping the vector of states $s_{t-1} = \{b_{t-1},\epsilon_t\}$ to the optimal decisions for $y_t = \{C_t, G_t, Y_t, \Pi_t, \tau_t, b_t, P_t^M, \lambda_{1t}, \lambda_{2t}, \lambda_{3t}\}$ for all $t \geq 0$.

Further insight into the trade-offs facing the policy maker can be generated considering specific FOCs. The FOC for taxation reveals a key feature of the underlying policy problem. In the absence of a need to satisfy the budget constraint through distortionary taxation, $\lambda_{3t} = 0$, the tax instrument would be used to eliminate the costs associated with the output-inflation trade-off implicit in the NKPC, $\lambda_{2t} = 0$. In other words, if it were not for the need to raise tax revenues to satisfy the government's budget constraint, taxes could be adjusted to eliminate any undesired movements in inflation, including that arising from mark-up shocks.

Similarly, the FOC for inflation highlights the nature of the inflationary bias contained in the model. The first two terms of the FOC capture the standard inflationary bias problem. The first term measures the costs of raising inflation, and the second term the output benefits of doing so (given inflationary expectations) which are evaluated positively when the economy operates at a suboptimally low level due to tax and monopolistic competition distortions. However, in the presence of debt the third term in the FOC for inflation captures an additional reason for wanting to raise inflation relative to expectations - the erosion of the real value of debt. Economic agents will anticipate that higher debt increases the government's desire to introduce inflation surprises, implying that inflationary expectations are increasing in the level of government debt, $E_t\left[M_1(b_t,\epsilon_{t+1})\right] > 0$ until inflation is sufficiently high to eliminate policy surprises (in the absence of further shocks). The state dependence of the inflationary bias will be key in driving the policy maker's desire to reduce debt relative to what we would observe under a time-inconsistent Ramsey policy - a tendency we label the "debt stabilization bias".

The remaining key FOC is for government debt which highlights the "debt stabilization bias". This bias can be understood by considering the FOC for debt, which can be simplified as,

$$\underbrace{P_t^M \lambda_{3t} - \widetilde{\beta} E_t\left[\frac{\lambda_{3t+1}}{\Pi_{t+1}}(1+\rho P_{t+1}^M)\right]}_{\text{tax smoothing}}$$
$$\underbrace{-\lambda_{3t} C_t^{\sigma}\left(\phi\epsilon^{-1}\beta E_t\left[M_1(b_t,\epsilon_{t+1})\right] - \left[(b_t - \rho\frac{b_{t-1}}{\Pi_t})E_t L_1(b_t,\epsilon_{t+1})\right]\right)}_{\text{debt stabilization bias}} = 0 \tag{17}$$

where $X_1(b_t,\epsilon_{t+1}) \equiv \partial X(b_t,\epsilon_{t+1})/\partial b_t$ for the functions, $X = \{L, M\}$. Equation (17) describes the policy maker's optimal debt policy which can be decomposed into two elements. The first line gives the optimal trade-off between current and future distortions associated with the need to satisfy the government's intertemporal budget constraint, that is achievable when the government can commit. The second line, captures wedges which are introduced when the policy maker is unable to commit, defining the debt stabilization bias.

Consider the debt policy implied by the standard trade-off between current and future distortions, reflected in the relationship between λ_{3t} and λ_{3t+1} in the first line of this expression. This reflects the tax-smoothing argument in Barro (1979), requiring that the marginal costs of taxation are smoothed over time.

Initially assume the policy maker is not myopic, so $\widetilde{\beta} = \beta$. In this case, when the return (adjusted for any covariance with the future costs of satisfying the government's intertemporal budget constraint, λ_{3t+1}) on holding the government bonds is equal to the household's rate of time preference, the distortions associated with satisfying the budget constraint are constant over time and steady-state debt will follow a random walk. Effectively, under tax smoothing, the policy maker trades-off the short-run costs of reducing the stock of debt against the discounted value of the long-term benefits. When debt service costs are consistent with the household/government's rate of time preference, these will be exactly balanced at a debt level which depends upon the history of the shocks hitting the economy.

Reintroducing myopia, such that $\widetilde{\beta} < \beta$, implies that when real interest rates differ from the policy maker's rate of time preference, then the policy maker will choose to tilt these distortions backwards (forwards) in time depending on whether debt service costs are below (above) the policy maker's rate of time preference. For example, when the real rate of return on debt, $r_t = E_t\left[\frac{1}{\Pi_{t+1}}\frac{(1+\rho P^M_{t+1})}{P^M_t}\right] = \beta^{-1}$, this implies $E_t\left[\frac{\lambda_{3t+1}}{\lambda_{3t}}\frac{1}{\Pi_{t+1}}\frac{(1+\rho P^M_{t+1})}{P^M_t}\right] = \widetilde{\beta}^{-1} > \beta^{-1}$ such that λ_{3t} is rising over time. The myopic policy maker would allow debt to rise.

However (17) is a generalized Euler equation, which, in the second line, includes partial derivatives of policy functions with respect to debt due to the time-consistency requirement. In general the form of these auxiliary functions is unknown, which is why the policy problem needs to be solved numerically. However, that numerical solution robustly gives clear signs for these derivatives, $M_1(b_t, \epsilon_{t+1}) > 0$ and $L_1(b_t, \epsilon_{t+1}) < 0$ which have an intuitive interpretation.

The first term on the second line of (17) reflects the fact that inflation expectations rise with debt levels (through the inflation biases discussed above - see the FOC for inflation), $M_1(b_t, \epsilon_{t+1}) > 0$, and since this is costly in the presence of nominal inertia, there is a desire to deviate from tax smoothing, in order to reduce debt and the associated increase in inflation. This is the first reason for wanting to reduce debt relative to the level that would be supported by a benevolent Ramsey planner.

The second term in square brackets in the second line captures the impact of higher debt on bond prices. Since higher debt raises inflation, which in turn reduces bond prices, $L_1(b_t, \epsilon_{t+1}) < 0$, this term also serves to encourage a reduction in debt levels, when debt is relatively short-term. Why? High, but falling debt levels imply an upward trend in bond prices which makes it cheaper to issue new debt, but more costly to buy-back the existing debt stock. As debt maturity is increased, the latter effect rises relative to the former, and hence the desire to reduce debt levels is reduced, ceteris paribus. This trade-off between tax-smoothing and time-consistency determines the equilibrium level of debt and inflation, where inflation is expected to be closer to zero as debt maturity rises, for a given level of debt.

4 Solution Method and Calibration

For the model described in the previous section, the equilibrium policy functions cannot be computed in closed form and local approximation methods are not applicable, as the model's steady state around which local dynamics should be approximated is endogenously determined as part of the model solution and thus a priori unknown. This necessitates the use of global solution methods. Specifically, the Chebyshev collocation method with time iteration. The detailed algorithm is presented in appendix E. In general, optimal discretionary policy problems can be characterized as a dynamic game between the private sector and successive governments. Multiplicity of equilibria is a common problem in dynamic games of this kind. Since the solution algorithm uses polynomial approximations, it is, in effect, searching only for continuous Markov-perfect equilibria where agents condition their strategies on payoff-relevant state variables, see Judd (2004) for a discussion.

Before solving the model numerically, the benchmark values of structural parameters must be specified. The calibration of parameters is summarized in Table 1. We set $\beta = (1/1.02)^{1/4} = 0.995$, which implies a 2% annual real interest rate. The intertemporal elasticity of substitution is set to one half ($\sigma = \sigma^g = 2$) which is in the middle of standard estimates.[7] The Labor supply elasticity is set to $\varphi^{-1} = 1/3$. The steady-state elasticity of substitution between intermediate goods is chosen as $\bar{\epsilon} = 14.33$, which implies a monopolistic markup of approximately 7.5%, similar to Siu (2004), and in the middle of conventional estimates.

The fiscal variables are calibrated to ensure the benchmark model mimics the key ratios in U.S. data over the period 1954-2008 as discussed in B and reported in the first column of Table 2. Parameter $\chi = 0.0076$ ensures government consumption is 7.8% of GDP, transfers are set to be 9% and the myopia of the policy maker is set to $\widetilde{\beta} = 0.982$ (an effective time horizon of just under 20 years) which supports an annualized steady-state debt-to-GDP ratio of 31%. The coupon decay parameter, $\rho = 0.95$, corresponds to around 5 years of debt maturity, consistent with U.S. data. The implied ratio of tax revenues to GDP in steady-state is slightly higher than the data average of 17.5% reflecting the fact that actual policy has often run a deficit in recent decades.

The price adjustment cost parameter, $\phi = 50$, implies, given the equivalence between the linearized NKPCs under Rotemberg and Calvo pricing (see Leith and Liu, 2016), that on average firms re-optimize prices every six months - in line with empirical evidence. Finally, the cost-push shock process is parameterized as $\rho_\epsilon = 0.939$ and $\sigma_\epsilon = 0.052$ in line with estimates in Chen et al. (2017) and Smets and Wouters (2003).

With this benchmark parameterization, the model solution generates a maximum Euler equation error over the full range of the grid is of the order of 10^{-6}. We plot these errors in F. As suggested by Judd (1998) , this order of accuracy is reasonable.[8]

5 Numerical Results

This section explores the properties of the equilibrium under optimal time-consistent policy. Subsection 5.1 considers the steady-state under a series of alternative parameterizations. Subsection 5.2 introduces switches in the degree of policy maker myopia enabling the model to mimic observed movements in the U.S. debt-to-GDP ratio. The optimal policy response to shocks is discussed in subsection 5.3 and the debt maturity decision is endogenized in subsection 5.4.

5.1 Steady State

Table 2 summarizes the steady state values for a variety of parameterizations, contrasting them with the data averages contained in column 1. Beginning with the benchmark calibration but temporarily removing policy maker myopia such that $\widetilde{\beta} = \beta$ - column 3 of Table 2. We can see the key trade-offs underpinning this steady-state equilibrium by considering the (deterministic) steady-state value of the FOC for debt, equation (17),

$$b(1 - \rho\frac{1}{\Pi})L_1(b, \bar{\epsilon}) = \phi\bar{\epsilon}^{-1}\beta M_1(b, \bar{\epsilon}) \tag{18}$$

[7] In the robustness exercises conducted in appendix J the elasticity for public spending is lowered in line with the evidence in Debortoli and Nunes (2013). However, this does not affect the key results.

[8] All other model variants considered are equally well approximated - these results are available upon request.

As noted above, the numerical solution of the policy problem implies $L_1(b,\bar{\epsilon}) < 0$ and $M_1(b,\bar{\epsilon}) > 0$. Assuming $\rho < \Pi$, this equation can only hold with a negative debt stock.[9] This is indeed what we find with $\frac{bP^M}{4Y} = -153\%$ and a steady-state inflation rate of -1.1%. In this equilibrium the policy maker has accumulated assets, but these fall short of the war chest level needed to support the first best allocation.[10] There is a steady-state deflation which ensures the policy maker is not tempted to introduce any further surprise deflation to increase the value of the assets it has accumulated.

Introducing policy maker myopia can overturn this result - see the second column of Table 2, labeled "benchmark". The benchmark has been calibrated to replicate a positive debt-to-GDP ratio of 31% and government consumption to output of 7.8%.[11] The steady-state rate of inflation this implies is 3%. The key equation defining this steady-state is the FOC for debt given by

$$b(1-\rho\frac{1}{\Pi})L_1(b,\bar{\epsilon}) = \phi\bar{\epsilon}^{-1}\beta M_1(b,\bar{\epsilon}) - C^{-\sigma}P^M(1-\frac{\widetilde{\beta}}{\beta}) \tag{19}$$

where the myopia can turn the RHS of this condition negative, thereby supporting a positive steady-state debt-to-GDP ratio. The debt stabilization bias is reduced, as the policy maker is less inclined to incur the costs of debt reduction in order to achieve longer-term benefits. It is notable that this change does little to affect the other key fiscal ratios of government consumption and taxation relative to GDP.

Column 4 increases policy maker myopia further to $\widetilde{\beta} = 0.975$, which is equivalent to reducing the policy maker's time horizon from 20 to 12 years. This more than doubles the steady-state debt-to-GDP ratio to 75.6% and inflation rises to 4.5%.

Increasing the flexibility of prices means both that the costs of inflation are lower, and that monetary policy is less effective in affecting the real economy. As a result the government is able to sustain a higher debt-to-GDP ratio which rises by 5.5%, as they are less driven to reduce the state-dependent inflationary bias problem. This leads to a larger steady-state rate of inflation of 3.8%, but it should be remembered that inflation is now less costly. Finally, reducing the mark-up is important since it implies the inflationary bias problem is lower for a given level of debt. As a result the desire to influence the state-dependent inflationary bias problem by reducing debt is less - the debt stabilization bias has been reduced. This leads to a substantial increase in the steady-state debt-to-GDP ratio to almost 90% and an associated increase in the steady-state rate of inflation to 3.7%.

Table 3, considers the impact of changes in the maturity structure of debt. Column 1 adopts the common assumption that debt is only of a single period's duration (one quarter in the context of the model parameterization). In this case the steady-state debt-to-GDP ratio

[9] No parameter permutations have been found which imply $\rho > \Pi$ such that the model without myopia can sustain a positive steady-state debt stock. Intuitively, unless debt stocks are negative, the economy remains sufficiently distorted that the inflationary bias problem ensures $\Pi > \rho$.

[10] The war chest asset stock would be 4,636% of GDP.

[11] An alternative device, that has been used in the literature (see for example Schmitt-Grohe and Uribe (2004b) and Niemann et al. (2013)), is to introduce a monetary friction to generate a positive steady-state debt-to-GDP ratio. Embedding such a device in the current model (see appendix G) can achieve this aim but not robustly. It is only when price stickiness is reduced to implausibly low levels ($\phi < 4$, an effective average price duration of less than 4 months) that the debt-to-GDP ratio turns mildly positive.

turns negative, -11% and inflation is 3.5%. While, increasing debt maturity to 30 years, leads to a significant increase in the debt-to-GDP ratio to over 102% of GDP and inflation to over 5%. This reflects the discussion above - longer maturity debt reduces the debt stabilization bias allowing the government to sustain a higher steady-state debt-to-GDP ratio.

In summary, myopia, monopolistic competition distortions and debt maturity are the key drivers of the equilibrium rate of inflation and debt-to-GDP ratio, while other endogenously determined steady-state fiscal ratios are largely unaffected by these changes. This highlights the importance of the state-dependent inflationary bias and the associated debt stabilization bias in jointly determining the equilibrium outcomes for inflation and debt.

5.2 Transition Dynamics

The model, despite macthing key fiscal data averages, cannot capture the key trends in the debt-to-GDP ratio seen in the data. For example, the standard deviation of the annualized debt-to-GDP ratio is only 0.7% under the benchmark calibration despite the equivalent volatility in the data being 9%. This implies that the fiscal consequences of mark-up shocks are insufficient to capture the movements in debt despite being calibrated in line with empirical estimates of such shock processes.[12] Therefore, in order to generate plausible movements in the debt-to-GDP ratio, there is a need to go beyond standard economic shocks and consider political frictions.

Specifically, the degree of policy maker myopia is assumed switch between two regimes, $\{\widetilde{\beta}_L, \widetilde{\beta}_H\}$ where $\widetilde{\beta}_L > \widetilde{\beta}_H$ where the former 'L' regime has a low degree of myopia and correspondingly supports a lower level of debt. Conversely, the high myopia regime is consistent with a higher debt level. There is an associated transition probability matrix governing the evolution of this two-state Markov process, $\begin{bmatrix} p_L & 1-p_L \\ 1-p_H & p_H \end{bmatrix}$ where p_i is the probability of remaining in regime i $(i = H, L)$ given we are currently regime i and $1-p_i$ is the probability of exit to the other regime j, $, j = (H, L), j \neq i$. The policy maker is assumed to not be in conflict with their future selves but to discount the future in line with whatever degree of myopia is in place at the time. As a result, the degree of myopia becomes an additional state variable so that the value function is defined as,

$$V(b_{t-1}, \epsilon_t, \widetilde{\beta}_{i,t}) = \max\left\{\frac{C_t^{1-\sigma}}{1-\sigma} + \chi\frac{G_t^{1-\sigma_g}}{1-\sigma_g} - \frac{(Y_t/A_t)^{1+\varphi}}{1+\varphi} + \widetilde{\beta}_{i,t}E_t\left[V(b_t, \epsilon_{t+1}, \widetilde{\beta}_{i,t+1})\right]\right\}$$

subject to the same constraints as before but where all auxiliary functions are based on this expanded state-space where $\widetilde{\beta}_{it} = \widetilde{\beta}_L$ or $\widetilde{\beta}_H$. The implications of this model extension for the description of optimal policy are outlined in H.

The calibration of this Markov switching process follows Chen et al. (2018) in identifying key shifts in the trend of the U.S. debt-to-GDP ratio - see Figure 1. Between 1954 and the first budget of the Reagan presidency in 1981 debt is on a downward trend. Similarly following Clinton's first budget until the first budget of the George W. Bush there is a

[12] Other shocks such as technology and transfer shocks are also unable to do so. Even allowing for temporarily unstable paths for transfers as in Bi et al. (2013) cannot generate data-consistent movements in debt-to-GDP ratios as the policy maker aggressively raises taxes to finance the rising transfers.

sustained reduction in the debt-to-GDP ratio. We label these episodes as being periods of low myopia. In contrast the periods of rising debt-to-GDP ratios covering all other periods are labeled as high myopia. Given this labeling the implied transition matrices between the two regimes can be estimated as, $\begin{bmatrix} 0.9859 & 1-0.9859 \\ 1-0.9868 & 0.9868 \end{bmatrix}$. $\widetilde{\beta}_L = 0.9866$ and $\widetilde{\beta}_H = 0.9759$ are chosen to replicate the peaks and troughs of the debt-to-GDP ratio found in the data, while the remainder of the benchmark calibration is retained. The success of this exercise can be seen in Figure 1 where the model implied dynamics of the debt-to-GDP ratio track the data both in the sense of ensuring the model can achieve the highs and lows seen in the data, but also the pace at which debt increases or decreases over time.

The first set of experiments looks at the transitions between high and low debt regimes. The solid line in Figure 3 plots the movements of key variables as a relative patient policy maker seeks to reduce debt (as was the case following the end of WWII). Similarly, the debt build-up from the 1980s onwards can be explored by examining the implications of a relatively myopic policy maker inheriting a low level of debt. In both cases the transitional dynamics are strikingly different from the ultimate steady-state (conditional on remaining in the particular myopia regime). A relatively patient government inheriting a large debt stock faces, for a given rate of inflation, greater incentives to induce inflation surprises to reduce that debt burden. This induces them to raise taxation sharply and to a lesser extent reduce government consumption to facilitate the reduction in debt. At the same time monetary policy is tightened to partially offset the increase in inflation. In the longer term, the successful reduction in the debt-to-GDP ratio allows the economy to sustain lower taxes, higher government consumption and lower inflation.

The converse is true when a relatively myopic government inherits a low debt stock. Since they care less about the future costs of servicing debt, their incentives to reduce a given level of debt through surprise inflation are lower. This enables them to dramatically reduce taxes and, to a lesser extent, increase government consumption in the short-run, while simultaneously enjoying relatively low inflation. Indeed it is only when the myopic government has raised the debt-to-GDP ratio by around 15% relative to the patient policy maker that the paths of inflation cross. However, ultimately the myopic policy maker suffers from higher taxation, lower government consumption and higher inflation as a result of the debt they accumulate in the long-run.

A key element in this is the maturity of the debt stock. Table 3 shows that increasing debt maturity from the common assumption of single period debt to the ultra long maturity of 30 years raises the steady-state debt-to-GDP ratio from -11% to 102%. It also impacts the transitional dynamics. In Figure 3 the initial debt stock is fixed to be common across all experiments at 58% of GDP and the Figure then describes the transition to the steady-state. The shorter the maturity structure of the debt, the more rapidly the policy maker undertakes their fiscal consolidation. Consistent with the analysis above, the inflationary bias problem is notably worse as debt maturity shortens implying much higher rates of inflation for an identical state of the economy. This in turn encourages the policy maker to reduce debt levels more rapidly and to a lower steady-state level when debt maturity is shorter i.e. the debt stabilization bias is greater for a shorter maturity debt stock.

5.3 Responding to Shocks

In the context of a model which mimics the major movements in the U.S. debt-to-GDP ratio, this subsection considers how debt levels affect the optimal policy response to shocks. In the standard New Keynesian economy the only shocks generating meaningful policy trade-offs for the policy maker are cost-push/mark-up shocks. If we remove all the fiscal elements of our model and apply a mark-up shock which raises the desired mark-up $\frac{\varepsilon_t}{\varepsilon_t - 1}$ by 0.5% then the optimal monetary policy response is to tighten policy to reduce inflation until the output costs of further monetary tightening are too great. The paths for output, inflation and interest rate under such a policy are given by the green dotted lines in the bottom three sub-panels of Figure 4.

Adding distortionary taxation to such a model potentially introduces a very effective policy instrument for dealing with such shocks. Temporarily ignoring the implications for government debt of such a policy, the tax rate entering the NKPC could be varied to offset the impact of the variations in ε_t. Figure 4 shows the reduction in taxation which would achieve this negation of the inflationary and output consequences of a positive mark-up shock and leave the economy at its steady-state - see the dotted magenta line in the tax rate sub-panel of Figure 4.

Turning now to the benchmark model, such a fiscal response to shocks is tempered by the fact that the policy maker must also ensure fiscal solvency and does not have access to lump-sum taxes with which to do so. Figure 4 plots the optimal time-consistent response to a mark-up shock conditional on being in the high (solid blue lines) or low (dashed red lines) debt regime. The existence of debt amplifies the impact of the shock, especially when we are in the high debt regime. Moreover, although tax cuts could in theory offset the inflationary consequences of the mark-up shock (the dotted magenta line in Figure 4) this would exacerbate the increase in debt which drives the inflationary bias problem discussed above. As a result the policy maker *raises* tax rates to ensure that debt falls as a more effective way of mitigating the inflationary consequences of the mark-up shock. Nevertheless the higher tax rates do increase inflation and monetary policy is tightened to help offset that. The end result is that the response to the mark-up shock is overwhelmingly driven by the desire to reduce debt through tax increases and thereby mitigate the state-dependent inflationary bias problem. Government spending largely moves in line with output such that there is negligible variation in the ratio of G/Y- government consumption is hardly used as an instrument of either macroeconomic or fiscal stabilization.[13]

5.4 Debt Management and the Debt Stabilization Bias

Up until this point, the level of debt maturity has been held fixed by parameterizing ρ. This subsection allows for the policy maker to have some control over the maturity structure as part of the time-consistent optimal policy problem, by allowing them to issue a mixture

[13] If the intertemporal elasticity of substitution for government consumption is reduced to $\sigma_g = 1$ in line with the evidence summarized in Debortoli and Nunes (2013), the standard deviation of the G/Y ratio rises from 0.8% to 1.4%, which is closer to the data average of 1.9%. However, this does not have a significant impact on either the transition between high/low debt regimes or the response to shocks other than to marginally enhance the role played by government consumption. See Appendix J.

of shorter and longer-maturity debt, possibly of opposite signs (i.e. one can be held as an asset and the other a liability). The reason why this is conjectured to be an interesting debt management policy is that the results obtained so far suggest that high debt levels imply a large state-dependent inflationary bias, which can turn to a deflationary bias when the government holds assets even although the economy is still operating at a less than efficient level. These biases are more acute, ceteris paribus, when the bond is short term. Therefore, issuing a short-term asset may offset the inflationary bias associated with a large stock of long-term debt.

To explore this possibility the supply of single-period bonds is no longer assumed to be zero. The wealth of the existing bondholders entering period t is now $D_t \equiv (1+\rho P_t^M)B_{t-1}^M + B_{t-1}^S$, the household then buys bonds, $P_t^M B_t^M + P_t^S B_t^S$ and as a result the government's budget constraint becomes,

$$P_t^M b_t^M + P_t^S b_t^S = \frac{b_{t-1}^S}{\Pi_t} + (1+\rho P_t^M)\frac{b_{t-1}^M}{\Pi_t} - \frac{W_t}{P_t}N_t\tau_t + G_t + tr$$

The remainder of the policy problem is unchanged, except for the fact that policy functions now have three arguments, the elasticity of substitution between goods, ϵ_t, and the levels of both maturities of bond, b_{t-1}^S and b_{t-1}. Appendix I derives the resultant FOCs.

By varying the relative proportions of these two types of bonds, the policy maker can influence the average maturity of the outstanding stock of debt and the associated inflation bias. Figure 5 plots the transition dynamics for the benchmark calibration, with and without the government possessing the ability to issue short-term bonds in addition to long-term debt. Despite the high overall debt-to-GDP ratio, the quantity of short-term debt issued is very low. Under optimal but time-consistent policy, the policy maker does not issue long-term debt to purchase short-term assets.[14] Instead, there is an extremely modest issuance of short-term debt, even when overall debt levels are very high. The short-term debt serves to support changes in the time-consistent policy mix. Specifically, monetary policy is relaxed relative to the case where no short-term debt is issued. This lower real interest rate slows the speed of fiscal consolidation allowing taxation to be lower in the short-run.

6 Conclusions

The existence of nominal debt induces a state-dependent inflation bias problem as the policy maker wishes to utilize inflation surprises to offset monopolistic competition and tax distortions and reduce the real value of debt. This temptation is greater with higher debt levels and shorter debt maturity, resulting in a debt stabilization bias as the policy maker deviates from Ramsey policy by returning debt to steady state to mitigate the associated inflation biases.

Allowing for switches in a modest degree of policy maker myopia allows the model to replicate the key trends in the post-WWII debt-to-GDP ratio in the United States. The response to shocks in such an environment seeks to avoid exacerbating these biases, while endogenizing the debt maturity decision reduces the speed of fiscal correction.

[14] Such portfolios have been used as a hedging device when policy makers can commit (see Debortoli et al. (2017) and Leeper and Leith (2017)).

A Tables

Parameter	Value	Definition
β	0.995	Quarterly discount factor, household.
$\widetilde{\beta}$	0.982	Quarterly discount factor, policy maker.
σ	2	Relative risk aversion coefficient
σ^g	2	Relative risk aversion coefficient for government spending
φ	3	Inverse Frish elasticity of labor supply
$\overline{\epsilon}$	14.33	Elasticity of substitution between varieties
ρ	0.95	Debt maturity structure (5 years)
χ	0.0076	Scaling parameter associated with government spending
ρ_ϵ	0.939	AR-coefficient of cost-push shock
σ_ϵ	0.052	Standard deviation of cost-push shock
ϕ	50	Rotemberg adjustment cost coefficient

Table 1: Parameterization

Variable	Data	Benchmark	No Myopia	Myopia $\widetilde{\beta} = 0.975$	Price Flexibility $\phi = 30$	Markup $\frac{\overline{\epsilon}}{\overline{\epsilon}-1} = 5\%$
$\frac{bP^M}{4Y}$	31.2%	31.2%	-152.9%	75.6%	36.7%	89.8%
$(\Pi^4 - 1)$	3.5%/2.4%	3.0%	-1.1%	4.5%	3.8%	3.7%
$(R^4 - 1)$	5.66%/4.9%	5.1%	0.9%	6.7%	5.9%	5.8%
Y	N.A.	0.977	0.985	0.975	0.977	0.980
G/Y	7.84%	7.82%	7.93%	7.76%	7.81%	7.75%
τ	17.5%	18.9%	15.3%	19.8%	19.0%	19.5%

Table 2: Steady-State: Myopia, Price Flexibility and Monopolistic Competition. Over the full sample the average inflation rate was 3.5% (with a standard deviation of 2.3%), while following the Great Moderation (post 1985) the average inflation rate falls to 2.4% with a standard deviation of 0.76%.

Variable	Benchmark	1 Qtr Maturity $\rho = 0$	1 Yr Maturity $\rho = 7538$	10 Yr Maturity $\rho = 0.9799$	30 Yr Maturity $\rho = 0.9966$
$\frac{bP^M}{4Y}$	31.2%	-11.1%	12.8%	53.6%	102.0%
$(\Pi^4 - 1)$	3.0%	1.5%	2.5%	3.62%	5.1%
$(R^4 - 1)$	5.1%	3.5%	4.6%	5.7%	7.2%
Y	0.977	0.979	0.978	0.976	0.973
G/Y	7.82%	8.01%	7.80%	7.83%	7.82%
τ	18.9%	18.2%	18.4%	19.4%	20.4%

Table 3: Steady-State: Maturity

B Figures

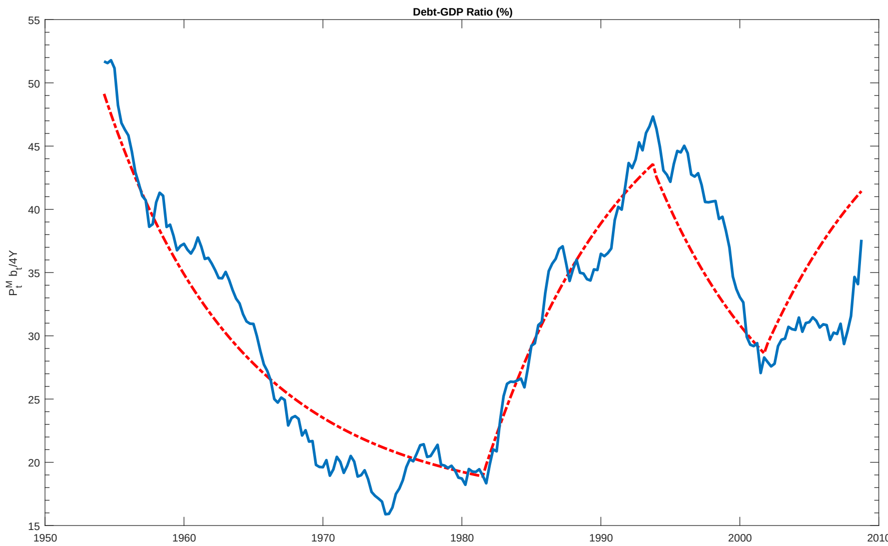

Figure 1: U.S. debt-to-GDP Ratio and Model Simulation. Solid line is the U.S. debt-to-GDP ratio between 1954 and 2008. For data source see B. The red dashed line is the simulated debt-to-GDP from benchmark model assuming higher policy maker myopia between first Reagan and Clinton administration budgets, and following George W. Bush administration's first budget.

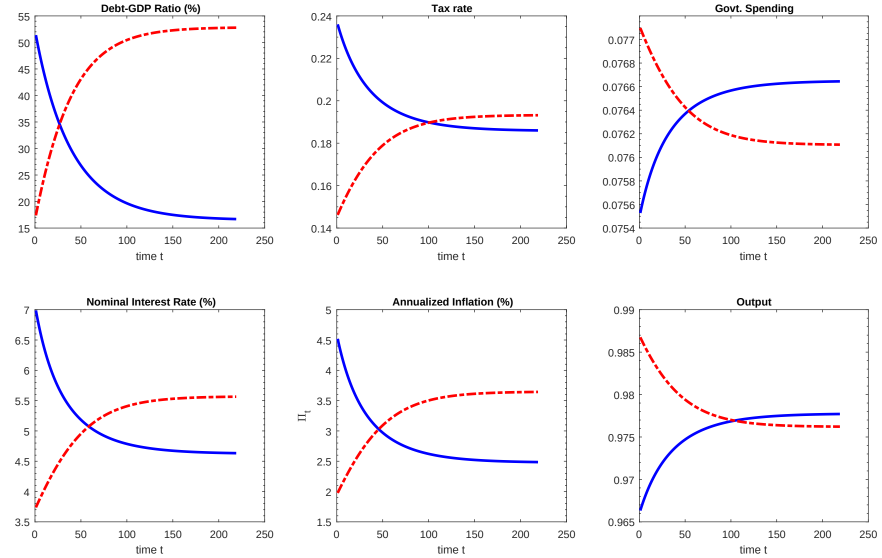

Figure 2: Transition between High/Low Debt Regimes. Blue solid line represents the transition from the high myopia/high debt regime to the low myopia/low debt regime. Red dot-dashed line is the opposite transition from low myopia/debt regime to high myopia/debt regime.

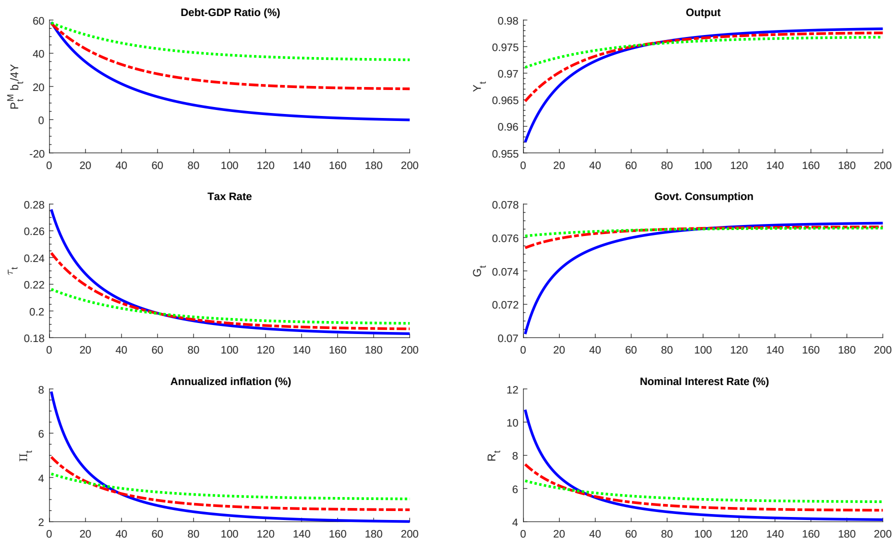

Figure 3: Debt Maturity and Fiscal Consolidation. All figures start from a debt-to-GDP of 58% and plot the transition to a low myopia/debt steady-state across different debt maturities. 1 year debt (solid blue line), 5 year maturity (red dot-dash line), 10 year maturity (green dotted line).

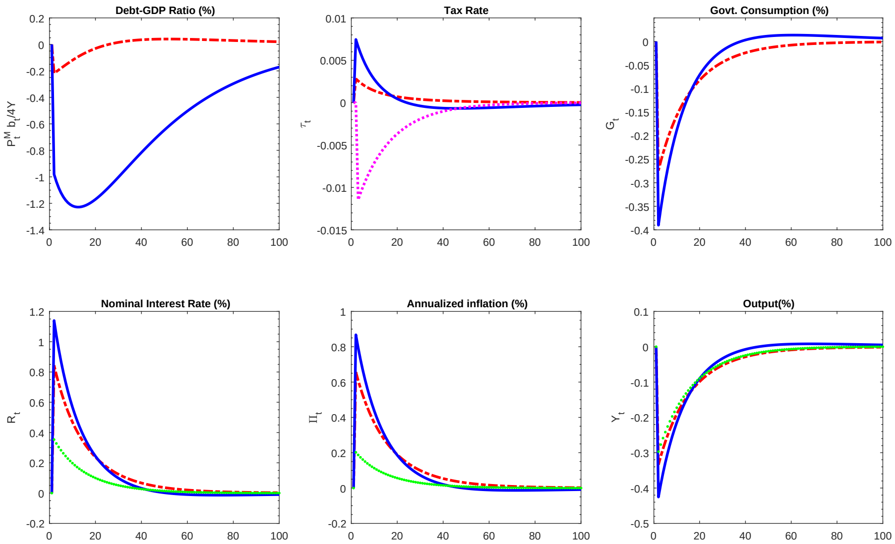

Figure 4: Impulse Response to Mark-Up Shock under High/Low Debt Regimes Government consumption and output measured as percentage deviation from steady-state. All other variations as deviation from steady-state. New Keynesian model without fiscal policy - green dotted line. Hypothetical tax rate which would offset shock - dotted magenta line. Monetary and fiscal response under high myopia/debt regime - blue solid line. Monetary and fiscal response under low myopia/debt regime - red dot-dash line.

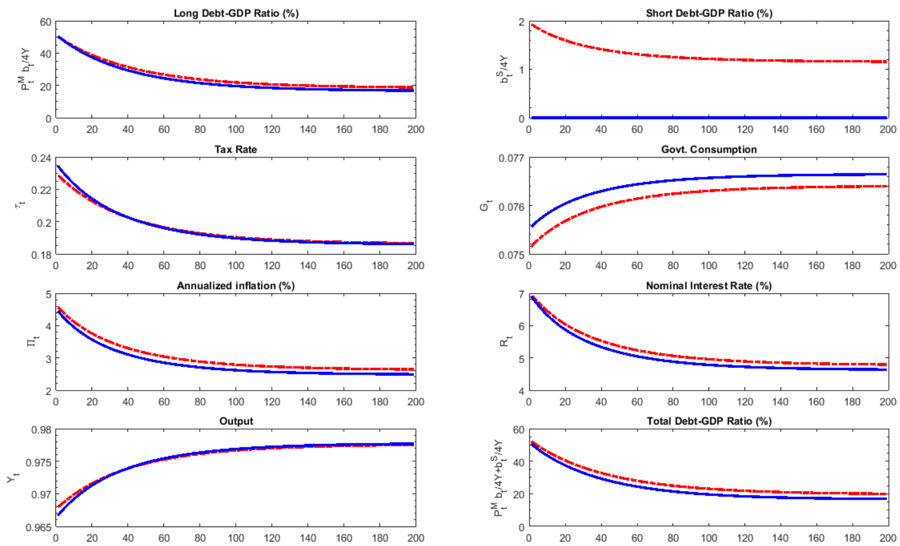

Figure 5: Endogenous Debt Maturity and Fiscal Consolidation. Endogenous debt maturity - solid blue line. Benchmark case of exogenous debt maturity - red dot-dash line.

Appendices

A Related Literature

The current paper is related to several strands of the optimal monetary and fiscal policy literature and the following discussion highlights those that are most closely related in terms of topics and numerical methods.

The contribution of the paper is most closely related to the literature that studies optimal fiscal and monetary policy in sticky price New Keynesian models using non-linear solution techniques. Following the work of Schmitt-Grohe and Uribe (2004b) and Siu (2004), Faraglia et al. (2013) solve a Ramsey problem using a parameterized expectation algorithm (PEA) to examine the implications for optimal inflation of changes in the level and maturity of government debt. Similarly, Leeper and Zhou (2013) consider a model similar to the current one, finding that inflation surprises are a small but significant part of the optimal policy response to shocks. We study the discretionary equivalent of this policy, which is radically different in terms of equilibrium outcomes. Niemann and Pichler (2011) globally solve for optimal fiscal and monetary policies under both commitment and discretion in an economy featuring a cash-in-advance constraint which alters the inflationary bias problem relative to that obtained in our more standard cashless New Keynesian model.[15] Additionally, they do not consider debt levels as large as recently observed in a number of advanced economies. Niemann et al. (2013) study time-consistent policy in the model of Schmitt-Grohe and Uribe (2004b) and identify a simple mechanism that generates inflation persistence. Government spending is exogenous in the latter two papers which also do not consider long-term debt. Similarly, abstracting from long-term debt, Matveev (2014) compares the efficacy of discretionary government spending and labor income taxes for the purpose of fiscal stimulus at the liquidity trap. In contrast the analysis presented here considers large deviations of debt from steady-state and debt of different maturities (both features which can radically affect the optimal policy response to shocks), time-consistent optimal policy making, and endogenous determination of the maturity structure and government consumption as part of the policy problem.

Aside from the relatively small literature exploring optimal monetary and fiscal policy in non-linear New Keynesian models, there is a vast literature on Ramsey fiscal and monetary policy in the tradition of Lucas and Stokey (1983), which tends to focus on real or flexible-price economies. In flexible-price environments, the government's problem consists in financing an exogenous stream of public spending by choosing the least disruptive combination of inflation and distortionary income taxes. In an incomplete-markets version of Lucas and Stokey (1983), Aiyagari et al. (2002) simulate the model globally and show that the level of welfare in Ramsey economies with and without real state-contingent debt is virtually the same. In addition, they reaffirm the random-walk results of debt and taxes from Barro (1979). Angeletos et al. (2013) introduce collateral constraints and a liquidity role for government bonds into Aiyagari et al. (2002). They use the Value Function Iteration (VFI) method to globally solve the modified model and find that the steady-state level of

[15] Monetary frictions are sometimes introduced as a means of ensuring a positive steady-state debt to GDP ratio. This modeling device is discussed in Appendix G.

debt is no longer indeterminate, when government bonds can serve as collateral. Cao (2014) extends Angeletos et al. (2013) with long-term debt and studies how the cost of inflation for commercial banks affects the design of fiscal and monetary policy. Likewise, Faraglia et al. (2014) use PEA methods to solve a Ramsey problem with incomplete markets and long-term bonds. They show that many features of optimal policy are sensitive to the introduction of long-term bonds, in particular tax variability and the long run behavior of debt. The current findings convey the same message that maturity lengths like those observed in actual economies can substantially alter the nature of optimal policies, but the policy problem in a sticky price economy where the policy maker is unable to commit is fundamentally different.

There is also a literature on optimal fiscal and monetary policy in monetary models, which do not contain nominal inertia, but may contain a cost to inflation. Schmitt-Grohe and Uribe (2004a) study Ramsey policy in a flexible-price model with cash-in-advance constraint, which essentially extends the model of Lucas and Stokey (1983) to an imperfectly competitive environment. A global numerical method is used to characterize the dynamic properties of the Ramsey allocation. In a cash-in-advance model, Martin (2009) studies the time consistency problems that arise from the interaction between debt and monetary policy, since inflation reduces the real value of nominal liabilities. He uses projection methods to deal with the generalized Euler equations, see also Martin (2011), Martin (2013) and Martin (2014) where time consistent policies are studied in variants of the monetary search model of Lagos and Wright (2005). Monetary frictions are considered in Section G, but most of the analysis abstracts from such frictions and emphasizes nominal price stickiness as the conventional approach to generating sizable real effects from monetary policy.

Moving away from models which jointly model monetary and fiscal policy, there is also a literature on optimal time-consistent fiscal policy in real models. This literature typically focuses on Markov-perfect policy, where households' and the government's policy rules are functions of payoff-relevant variables only. Local approximations around a non-stochastic steady state are typically infeasible for these models, since optimal behavior is characterized by generalized Euler equations that involve the derivatives of some equilibrium decision rules, and thus it is impossible to compute the steady state independent of these rules. Hence global solution methods are required. Klein and Rios-Rull (2003) compare the stochastic properties of optimal fiscal policy without commitment with those properties under a full-commitment policy in a neoclassical growth model with a balanced government budget, see also Krusell et al. (2006) and Klein et al. (2008). Ortigueira (2006) studies Markov-perfect optimal taxation under a balanced-budget rule, while Ortigueira et al. (2012) deal with the case of unbalanced budgets. In a version of Lucas and Stokey (1983) model with endogenous government expenditure, Debortoli and Nunes (2013) find that when governments cannot commit, debt is no longer indeterminate and often converges to a steady-state with no debt accumulation at all. This is a quite striking difference in the behavior of debt between the full commitment and the no-commitment cases. Similarly, Grechyna (2013) also considers endogenous government spending in the environment of Lucas and Stokey (1983) with only one-period debt and shows that around the steady state, the properties of the fiscal variables are very similar, regardless of commitment assumptions. More recently, Debortoli et al. (2017) consider a Lucas and Stokey (1983) economy without state-contingent bonds and commitment, and show that the government actively manages its debt positions and can approximate optimal policy by confining its debt instruments to consols. Solving the policy problem set out below shares the same technical problem due to the presence of generalized Euler equations, but nominal rigidities make the model setup quite different from these papers.

Finally, the new political economy literature (see Alesina and Passalacqua (2017) for a comprehensive survey) considers how various aspects of the political process affect the accumulation of government debt, and the tendency of some economies to be prone to a deficit bias. While there are numerous mechanisms through which political economy considerations influence fiscal policy, including the use of debt as a strategic variable, wars of attrition over who bears the burden of fiscal reforms and the nature of the budgetary process itself, in essence these political frictions imply that policy makers may not fully internalize the long-term benefits of lower debt, while remaining acutely aware of the short-term costs of any fiscal correction. This implicit myopia is captured informally, by considering the implications of the policy maker discounting the future at a rate which is higher than that of society as a whole.

B Data

We follow Chen et al. (2018) and Bianchi and Ilut (2017) in constructing our fiscal variables. The data for government spending, tax revenues and transfers, are taken from National Income and Product Accounts (NIPA) Table 3.2 (Federal Government Current Receipts and Expenditures) released by the Bureau of Economics Analysis. These data series are nominal and in levels.

Government Spending. Government spending is defined as the sum of consumption expenditure (line 21), gross government investment (line 42), net purchases of nonproduced assets (line 44), minus consumption of fixed capital (line 45), minus wage accruals less disbursements (line 33).

Total tax revenues. Total tax revenues are constructed as the difference between current receipts (line 38) and current transfer receipts (line 16).

Transfers. Transfers is defined as current transfer payments (line 22) minus current transfer receipts (line 16) plus capital transfers payments (line 43) minus capital transfer receipts (line 39) plus subsidies (line 32).

Federal government debt. Federal government debt is the market value of privately held gross Federal debt, which is downloaded from Dallas Fed web-site

The above three fiscal variables are normalized with respect to Nominal GDP. **Nominal GDP** is taken from NIPA Table 1.1.5 (Gross Domestic Product).

Real GDP. Real GDP is take download from NIPA Table 1.1.6 (Real Gross Domestic Product, Chained Dollars)

The GDP deflator. The GDP deflator is obtained from NIPA Table 1.1.5 (Gross Domestic Product).

Effective Federal Funds Rate. Effective Federal Funds Rate is taken from the St. Louis Fed website.

The implied ratios are presented in the first column of Table 2.

C Summary of Model

We now summarize the model and its steady state before turning to the time-consistent policy problem. Consumption Euler equation,

$$\beta R_t E_t \left\{ \left(\frac{C_t}{C_{t+1}} \right)^{\sigma} \left(\frac{P_t}{P_{t+1}} \right) \right\} = 1 \tag{20}$$

Pricing of longer-term bonds,

$$\beta E_t \left\{ \left(\frac{C_t}{C_{t+1}} \right)^{\sigma} \left(\frac{P_t}{P_{t+1}} \right) \left(1 + \rho P^M_{t+1}\right) \right\} = P^M_t \tag{21}$$

Labour supply,

$$N_t^{\varphi} C_t^{\sigma} = (1 - \tau_t) \left(\frac{W_t}{P_t} \right) \equiv (1 - \tau_t) w_t$$

Resource constraint,

$$Y_t \left[1 - \frac{\phi}{2} \left(\Pi_t - 1 \right)^2 \right] = C_t + G_t \tag{22}$$

Phillips curve,

$$\begin{aligned} 0 = &(1 - \epsilon_t) + \epsilon_t mc_t - \phi \Pi_t \left(\Pi_t - 1 \right) \\ &+ \phi \beta E_t \left[\left(\frac{C_t}{C_{t+1}} \right)^{\sigma} \frac{Y_{t+1}}{Y_t} \Pi_{t+1} \left(\Pi_{t+1} - 1 \right) \right] \end{aligned} \tag{23}$$

Government budget constraint,

$$P^M_t b_t = (1 + \rho P^M_t) \frac{b_{t-1}}{\Pi_t} - \left(\frac{\tau_t}{1 - \tau_t} \right) (Y_t)^{1+\varphi} C_t^{\sigma} + G_t + tr \tag{24}$$

Technology,

$$Y_t = N_t \tag{25}$$

Marginal costs,

$$mc_t = W_t / P_t = (1 - \tau_t)^{-1} Y_t^{\varphi} C_t^{\sigma}$$

The objective function for social welfare is given by,

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} + \chi \frac{G_t^{1-\sigma_g}}{1-\sigma_g} - \frac{(Y_t)^{1+\varphi}}{1+\varphi} \right) \tag{26}$$

There are two state variables, real debt b_t and the elasticity of substitution between good varieties, ϵ_t.

C.1 The Deterministic Steady State

Given the system of non-linear equations, the corresponding steady-state system can be written as follows:

$$\frac{\beta R}{\Pi} = 1$$

$$\frac{\beta}{\Pi}\left(1+\rho P^M\right) = P^M$$

$$(1-\tau)w = N^{\varphi} C^{\sigma}$$

$$Y\left[1-\frac{\phi}{2}\left(\Pi-1\right)^2\right] = C+G$$

$$(1-\epsilon)+\epsilon mc+\phi\left(\beta-1\right)\left[\Pi\left(\Pi-1\right)\right] = 0$$

$$P^M b = (1+\rho P^M)\frac{b}{\Pi} - \left(\frac{\tau}{1-\tau}\right) Y^{1+\varphi} C^{\sigma} + G + tr$$

$$Y = N$$

$$mc = w = (1-\tau)^{-1} Y^{\varphi} C^{\sigma}$$

$$P^M = \frac{\beta}{\Pi-\beta\rho}$$

$$mc = w = \frac{\epsilon-1}{\epsilon}$$

$$\frac{C}{Y} = \left[(1-\tau)\left(\frac{\epsilon-1}{\epsilon}\right)\right]^{1/\sigma} Y^{-\frac{\varphi+\sigma}{\sigma}}$$

$$\frac{G}{Y} = 1-\frac{C}{Y} = 1-\left[(1-\tau)\left(\frac{\epsilon-1}{\epsilon}\right)\right]^{1/\sigma} Y^{-\frac{\varphi+\sigma}{\sigma}}$$

$$P^M b = \frac{\beta}{1-\beta}\left[\tau\left(\frac{\epsilon-1}{\epsilon}\right)-\frac{G}{Y}\right] Y$$

Note that,

$$Y^{\varphi+\sigma}\left(1-\frac{G}{Y}\right)^{\sigma} = (1-\tau)\left(\frac{\epsilon-1}{\epsilon}\right) \tag{27}$$

which will be used to contrast with the allocation that would be chosen by a social planner.

D First-Best Allocation

In some analyses of optimal fiscal policy (e.g., Aiyagari et al., 2002), it is desirable for the policy maker to accumulate a 'war chest' which pays for government consumption and/or fiscal subsidies to correct for other market imperfections. In order to assess to what extent our optimal, but time-consistent policy attempts to do so, it is helpful to define the level of government accumulated assets that would be necessary to mimic the social planner's allocation under the decentralized solution. The first step in doing so is defining the first-best allocation that would be implemented by the social planner. The social planner ignores the nominal inertia and all other inefficiencies, and chooses real allocations that maximize the representative consumer's utility, subject to the aggregate resource constraint and the aggregate production function. That is, the first-best allocation $\{C_t^*,\, N_t^*,\, G_t^*\}$ is the one that maximizes utility (26), subject to the technology constraint (25), and aggregate resource constraint $Y_t = C_t + G_t$.

The first order conditions imply that

$$(C_t^*)^{-\sigma} = \chi\,(G_t^*)^{-\sigma_g} = (N_t{}^*)^{\varphi} = (Y_t{}^*)^{\varphi}$$

That is, given the resource constraints, it is optimal to equate the marginal utility of private and public consumption to the marginal disutility of labor effort and the optimal share of government consumption in output is

$$\frac{G_t^*}{Y_t^*} = \chi^{\frac{1}{\sigma_g}}\,(Y_t{}^*)^{-\frac{\varphi+\sigma_g}{\sigma_g}}$$

In a deterministic steady state and assuming $\sigma = \sigma_g$, this implies the optimal share of government consumption in output is

$$\frac{G^*}{Y^*} = \left(1 + \chi^{-\frac{1}{\sigma}}\right)^{-1}$$

and the first-best level of steady-state output is given by,

$$(Y^*)^{\varphi+\sigma}\left(1 - \frac{G^*}{Y^*}\right)^{\sigma} = 1 \tag{28}$$

It is illuminating to contrast the allocation achieved in the steady state of the decentralized equilibrium with this first best allocation. We do this by finding policies and prices that make the first-best allocation and the decentralized equilibrium coincide. Appendix C shows that the steady-state level of output in the decentralized economy is given by,

$$Y^{\varphi+\sigma}\left(1 - \frac{G}{Y}\right)^{\sigma} = (1-\tau)\left(\frac{\epsilon - 1}{\epsilon}\right) \tag{29}$$

Comparing (29) and (28), and assuming the steady state share of government consumption is the same, then the two allocations will be identical when the labor income tax rate is set optimally to be,

$$\tau^* = 1 - \frac{\epsilon}{\epsilon - 1} = \frac{-1}{\epsilon - 1} \tag{30}$$

Notice that the optimal tax rate is negative, that is, it is effectively a subsidy which offsets the monopolistic competition distortion. This, in turn, requires that the government has accumulated a stock of assets defined as,

$$\frac{P^{M*}b^*}{4Y^*} = \frac{\beta}{4(1-\beta)}\left[\frac{-1}{\epsilon} - \left(1+\chi^{-\frac{1}{\sigma}}\right)^{-1} - \frac{tr}{Y}\right]$$

Using our benchmark calibration below, this would imply that a stock of assets of 4636% of GDP would be required to generate sufficient income to pay for government expenditure (consumption and fiscal transfers) and a labor income subsidy which completely offsets the effects of the monopolistic competition distortion. In the absence of policy maker myopia, the steady-state level of debt in our optimal policy problem while negative, falls far short of this 'war chest' value.

It is also interesting to note the implied optimal share of government spending in GDP that would be chosen by the social planner is 7.7% which is very close to that chosen by the policy maker in our decentralized (7.82%) distorted economy implying that G is 3.9% lower than the first best while GDP is 5.4% smaller than it would be under the social planner's allocation.

E Numerical Algorithm

This section describes the Chebyshev collocation method with time iteration used in the paper. See Judd (1998) for a textbook treatment of the involved numerical techniques.

Let $s_t = (b_{t-1}, \epsilon_t)$ denote the state vector at time t, where real stock of debt b_{t-1} is endogenous and elasticity of substitution between goods ϵ_t is exogenous and respectively, with the following laws of motion:

$$P_t^M b_t = (1+\rho P_t^M)\frac{b_{t-1}}{\Pi_t} - w_t N_t \tau_t + G_t + tr$$

$$\ln(\epsilon_t) = (1-\rho_\epsilon)\ln(\bar{\epsilon}) + \rho_\epsilon \ln(\epsilon_{t-1}) + \sigma_\epsilon \varepsilon_t,\ \varepsilon_t \sim N(0,1)$$

where $0 \leq \rho_\epsilon < 1$.

There are 7 endogenous variables and 3 Lagrangian multipliers. Correspondingly, there are 10 functional equations associated with the 10 variables $\left\{C_t, Y_t, \Pi_t, b_t, \tau_t, P_t^M, G_t, \lambda_{1t}, \lambda_{2t}, \lambda_{3t}\right\}$. Defining a new function $X : \mathbb{R}^2 \to \mathbb{R}^{10}$, in order to collect the policy functions of endogenous variables as follows:

$$X(s_t) = \left(C_t(s_t), Y_t(s_t), \Pi_t(s_t), b_t(s_t), \tau_t(s_t), P_t^M(s_t), G_t(s_t), \lambda_{1t}(s_t), \lambda_{2t}(s_t), \lambda_{3t}(s_t)\right)$$

Given the specification of the function X, the equilibrium conditions can be written more compactly as,

$$\Gamma\left(s_t, X(s_t), E_t\left[Z\left(X(s_{t+1})\right)\right], E_t\left[Z_b\left(X(s_{t+1})\right)\right]\right) = 0$$

where $\Gamma : \mathbb{R}^{2+10+3+3} \to \mathbb{R}^{10}$ summarizes the full set of dynamic equilibrium relationships, and

$$Z\left(X(s_{t+1})\right) = \begin{bmatrix} Z_1\left(X(s_{t+1})\right) \\ Z_2\left(X(s_{t+1})\right) \\ Z_3\left(X(s_{t+1})\right) \end{bmatrix} \equiv \begin{bmatrix} M(b_t, \epsilon_{t+1}) \\ L(b_t, \epsilon_{t+1}) \\ \left(\Pi_{t+1}\right)^{-1}\left(1+\rho P_{t+1}^M\right)\lambda_{3t+1} \end{bmatrix}$$

with

$$M(b_t, \epsilon_{t+1}) = (C_{t+1})^{-\sigma} Y_{t+1}\Pi_{t+1}(\Pi_{t+1} - 1)$$
$$L(b_t, \epsilon_{t+1}) = (C_{t+1})^{-\sigma}(\Pi_{t+1})^{-1}(1 + \rho P^M_{t+1})$$

and

$$Z_b(X(s_{t+1})) = \begin{bmatrix} \frac{\partial Z_1(X(s_{t+1}))}{\partial b_t} \\ \frac{\partial Z_2(X(s_{t+1}))}{\partial b_t} \\ \frac{\partial Z_3(X(s_{t+1}))}{\partial b_t} \end{bmatrix} \equiv \begin{bmatrix} \frac{\partial M(b_t,\epsilon_{t+1})}{\partial b_t} \\ \frac{\partial L(b_t,\epsilon_{t+1})}{\partial b_t} \\ \frac{\partial\left[(\Pi_{t+1})^{-1}\left(1+\rho P^M_{t+1}\right)\lambda_{3t+1}\right]}{\partial b_t} \end{bmatrix}$$

More specifically,

$$L_1(b_t, \epsilon_{t+1}) = \frac{\partial\left[(C_{t+1})^{-\sigma}(\Pi_{t+1})^{-1}(1 + \rho P^M_{t+1})\right]}{\partial b_t}$$

$$= -\sigma(C_{t+1})^{-\sigma-1}(\Pi_{t+1})^{-1}(1 + \rho P^M_{t+1})\frac{\partial C_{t+1}}{\partial b_t}$$
$$-(C_{t+1})^{-\sigma}(\Pi_{t+1})^{-2}(1 + \rho P^M_{t+1})\frac{\partial \Pi_{t+1}}{\partial b_t} + \rho(C_{t+1})^{-\sigma}(\Pi_{t+1})^{-1}\frac{\partial P^M_{t+1}}{\partial b_t}$$

and

$$M_1(b_t, \epsilon_{t+1}) = \frac{\partial\left[(C_{t+1})^{-\sigma} Y_{t+1}\Pi_{t+1}(\Pi_{t+1} - 1)\right]}{\partial b_t}$$

$$= -\sigma(C_{t+1})^{-\sigma-1}Y_{t+1}\Pi_{t+1}(\Pi_{t+1} - 1)\frac{\partial C_{t+1}}{\partial b_t} + (C_{t+1})^{-\sigma}\Pi_{t+1}(\Pi_{t+1} - 1)\frac{\partial Y_{t+1}}{\partial b_t}$$
$$+ (C_{t+1})^{-\sigma} Y_{t+1}(\Pi_{t+1} - 1)\frac{\partial \Pi_{t+1}}{\partial b_t} + (C_{t+1})^{-\sigma} Y_{t+1}\Pi_{t+1}\frac{\partial \Pi_{t+1}}{\partial b_t}$$

$$= -\sigma(C_{t+1})^{-\sigma-1}Y_{t+1}\Pi_{t+1}(\Pi_{t+1} - 1)\frac{\partial C_{t+1}}{\partial b_t} + (C_{t+1})^{-\sigma}\Pi_{t+1}(\Pi_{t+1} - 1)\frac{\partial Y_{t+1}}{\partial b_t}$$
$$+ (C_{t+1})^{-\sigma} Y_{t+1}(2\Pi_{t+1} - 1)\frac{\partial \Pi_{t+1}}{\partial b_t}$$

Note we are assuming $E_t[Z_b(X(s_{t+1}))] = \partial E_t[Z(X(s_{t+1}))]/b_t$, which is normally valid using the Interchange of Integration and Differentiation Theorem. Then the problem is to find a vector-valued function X that Γ maps to the zero function. Projection methods can be used.

Following the notation convention in the literature, we simply use $s = (b, \epsilon)$ to denote the current state of the economy $s_t = (b_{t-1}, \epsilon_t)$, and s' to represent next period state that evolves according to the law of motion specified above. The Chebyshev collocation method with time iteration, which we use to solve this nonlinear system, can be described as follows:

1. Define the collocation nodes and the space of the approximating functions:

   - Choose an order of approximation (i.e., the polynomial degrees) n_b and n_ϵ for each dimension of the state space $s = (b, \epsilon)$, then there are $N_s = (n_b + 1) \times (n_\epsilon + 1)$ nodes in the state space. Let $S = (S_1, S_2, ..., S_{N_s})$ denote the set of collocation nodes.

- Compute the $n_b + 1$ and $n_\epsilon + 1$ roots of the Chebychev polynomial of order $n_b + 1$ and $n_\epsilon + 1$ as

$$z_b^i = \cos\left(\frac{(2i-1)\pi}{2(n_b+1)}\right), \text{ for } i = 1, 2, ..., n_b + 1.$$
$$z_\epsilon^i = \cos\left(\frac{(2i-1)\pi}{2(n_\epsilon+1)}\right), \text{ for } i = 1, 2, ..., n_\epsilon + 1.$$

- Compute collocation points ϵ_i as

$$\epsilon_i = \frac{\epsilon_{max} + \epsilon_{min}}{2} + \frac{\epsilon_{max} - \epsilon_{min}}{2} z_\epsilon^i = \frac{\epsilon_{max} - \epsilon_{min}}{2}\left(z_\epsilon^i + 1\right) + \epsilon_{min}$$

for $i = 1, 2, ..., n_\epsilon + 1$, which map $[-1, 1]$ into $[\epsilon_{min}, \epsilon_{max}]$. Note that the number of collocation nodes is $n_\epsilon + 1$. Similarly, compute collocation points b_i as

$$b_i = \frac{b_{max} + b_{min}}{2} + \frac{b_{max} - b_{min}}{2} z_b^i = \frac{b_{max} - b_{min}}{2}\left(z_b^i + 1\right) + b_{min}$$

for $i = 1, 2, ..., n_b + 1$, which map $[-1, 1]$ into $[b_{min}, b_{max}]$. Note that

$$S = \{(b_i, \epsilon_j) \mid i = 1, 2, ..., n_b + 1,\ j = 1, 2, ..., n_\epsilon + 1\}$$

that is, the tensor grids, with $S_1 = (b_1, \epsilon_1)$, $S_2 = (b_1, \epsilon_2)$, ..., $S_{N_s} = (b_{n_b+1}, \epsilon_{n_\epsilon+1})$.

- The space of the approximating functions, denoted as Ω, is a matrix of two-dimensional Chebyshev polynomials. More specifically,

$$\Omega(S) = \begin{bmatrix} \Omega(S_1) \\ \Omega(S_2) \\ \vdots \\ \Omega(S_{n_\epsilon+1}) \\ \vdots \\ \Omega(S_{N_s}) \end{bmatrix} =$$

$$= \begin{bmatrix} 1 & T_0(\xi(b_1)T_1(\xi(\epsilon_1)) & T_0(\xi(b_1)T_2(\xi(\epsilon_1)) & \cdots & T_{n_b}(\xi(b_1)T_{n_\epsilon}(\xi(\epsilon_1)) \\ 1 & T_0(\xi(b_1)T_1(\xi(\epsilon_2)) & T_0(\xi(b_1)T_2(\xi(\epsilon_2)) & \cdots & T_{n_b}(\xi(b_1)T_{n_\epsilon}(\xi(\epsilon_2)) \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ 1 & T_0(\xi(b_1)T_1(\xi(\epsilon_{n_\epsilon+1})) & T_0(\xi(b_1)T_2(\xi(\epsilon_{n_\epsilon+1})) & \cdots & T_0(\xi(b_1)T_{n_\epsilon}(\xi(\epsilon_{n_\epsilon+1})) \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ 1 & T_0(\xi(b_{n_b+1})T_1(\xi(\epsilon_{n_\epsilon+1})) & T_0(\xi(b_{n_b+1})T_2(\xi(\epsilon_{n_\epsilon+1})) & \cdots & T_0(\xi(b_{n_b+1})T_{n_\epsilon}(\xi(\epsilon_{n_\epsilon+1})) \end{bmatrix}_{N_s \times N_s}$$

where $\xi(x) = 2\left(x - x_{min}\right) / \left(x_{max} - x_{min}\right) - 1$ maps the domain of $x \in [x_{min}, x_{max}]$ into $[-1, 1]$.

- Then, at each node $s \in S$, policy functions $X(s)$ are approximated by $X(s) = \Omega(s)\Theta_X$,
where

$$\Theta_X = \left[\theta^c, \theta^Y, \theta^\Pi, \theta^b, \theta^\tau, \theta^{\widetilde{P}}, \theta^G, \theta^{\lambda_1}, \theta^{\lambda_2}, \theta^{\lambda_3}\right]$$

is a $N_s \times 10$ matrix of the approximating coefficients.

2. Formulate an initial guess for the approximating coefficients, Θ_X^0, and specify the stopping rule ϵ_{tol}, say, 10^{-6}.

3. At each iteration j, we can get an updated Θ_X^j by implement the following time iteration step:

   - At each collocation node $s \in S$, compute the possible values of future policy functions $X(s')$ for $k = 1, ..., q$. That is,

   $$X(s') = \Omega(s')\Theta_X^{j-1}$$

   where q is the number of Gauss-Hermite quadrature nodes. Note that

   $$\Omega(s') = T_{j_b}(\xi(b'))T_{j_\epsilon}\left(\xi(\epsilon')\right)$$

   is a $q \times N_s$ matrix, with $b' = \widehat{b}(s;\theta^b)$, $\ln(\epsilon') = (1-\rho_\epsilon)\ln(\overline{\epsilon}) + \rho_\epsilon \ln(\epsilon) + z_k\sqrt{2\sigma_\epsilon^2}$, $j_b = 0, ..., n_b$, and $j_\epsilon = 0, ..., n_\epsilon$. The hat symbol indicates the corresponding approximate policy functions, so $\widehat{b}$ is the approximate policy for real debt, for example. Similarly, the two auxiliary functions can be calculated as follows:

   $$M(s') \approx \left(\widehat{C}(s';\theta^c)\right)^{-\sigma}\widehat{Y}(s';\theta^y)\widehat{\Pi}(s';\theta^\pi)\left(\widehat{\Pi}(s';\theta^\pi)-1\right)$$

   and,

   $$L(s') \approx \left(\widehat{C}(s';\theta^c)\right)^{-\sigma}\left(\widehat{\Pi}(s';\theta^\pi)\right)^{-1}\left(1+\frac{\rho\widehat{P^M}\left(s';\theta^{\widetilde{p}}\right)}{1-\rho\beta}\right)$$

   Note that we use $\widetilde{P}_t^M = (1-\rho\beta)\,P_t^M$ rather than P_t^M in numerical analysis, since the former is far less sensitive to maturity structure variations.

   - Now calculate the expectation terms $E\left[Z\left(X(s')\right)\right]$ at each node s. Let ω_k denote the weights for the quadrature, then

   $$E\left[M(s')\right] \approx \frac{1}{\sqrt{\pi}}\sum_{k=1}^{q}\omega_k\left(\widehat{C}(s';\theta^c)\right)^{-\sigma}\widehat{Y}(s';\theta^y)\widehat{\Pi}(s';\theta^\pi)\left(\widehat{\Pi}(s';\theta^\pi)-1\right) \equiv \overline{M}\left(s',q\right)$$

   $$E\left[L(s')\right] \approx \frac{1}{\sqrt{\pi}}\sum_{k=1}^{q}\omega_k\left(\widehat{C}(s';\theta^c)\right)^{-\sigma}\left(\widehat{\Pi}(s';\theta^\pi)\right)^{-1}\left(1+\frac{\rho\widehat{P^M}\left(s';\theta^{\widetilde{p}}\right)}{1-\rho\beta}\right) \equiv \overline{L}\left(s',q\right)$$

   and

   $$E_t\left[\left(\frac{1+\rho P_{t+1}^M}{\Pi_{t+1}}\right)\lambda_{3t+1}\right] \approx \frac{1}{\sqrt{\pi}}\sum_{k=1}^{q}\omega_k\left(\frac{1+\frac{\rho\widehat{P^M}\left(s';\theta^{\widetilde{p}}\right)}{1-\rho\beta}}{\widehat{\Pi}(s';\theta^\pi)}\right)\widehat{\lambda}_3(s';\theta^{\lambda_3}) \equiv \Lambda\left(s',q\right).$$

   Hence,

   $$E\left[Z\left(X(s')\right)\right] \approx E\left[\widehat{Z}\left(X(s')\right)\right] = \begin{bmatrix} \overline{M}\left(s',q\right) \\ \overline{L}\left(s',q\right) \\ \Lambda\left(s',q\right) \end{bmatrix}$$

   - Next calculate the partial derivatives under expectation $E\left[Z_b\left(X(s')\right)\right]$.

- Note that we only need to compute $\partial C_{t+1}/\partial b_t$, $\partial Y_{t+1}/\partial b_t$, $\partial \Pi_{t+1}/\partial b_t$ and $\partial P^M_{t+1}/\partial b_t$, which are given as follows:

$$\frac{\partial C_{t+1}}{\partial b} \approx \sum_{j_b=0}^{n_b} \sum_{j_\epsilon=0}^{n_\epsilon} \frac{2\theta^c_{j_b j_\epsilon}}{b_{max} - b_{min}} T'_{j_b}(\xi(b'))T_{j_\epsilon}(\xi(\epsilon')) \equiv \widehat{C}_b\left(s'\right)$$

$$\frac{\partial Y_{t+1}}{\partial b_t} \approx \sum_{j_b=0}^{n_b} \sum_{j_\epsilon=0}^{n_\epsilon} \frac{2\theta^y_{j_b j_\epsilon}}{b_{max} - b_{min}} T'_{j_b}(\xi(b'))T_{j_\epsilon}(\xi(\epsilon')) \equiv \widehat{Y}_b\left(s'\right)$$

$$\frac{\partial \Pi_{t+1}}{\partial b_t} \approx \sum_{j_b=0}^{n_b} \sum_{j_\epsilon=0}^{n_\epsilon} \frac{2\theta^\pi_{j_b j_\epsilon}}{b_{max} - b_{min}} T'_{j_b}(\xi(b'))T_{j_\epsilon}(\xi(\epsilon')) \equiv \widehat{\Pi}_b\left(s'\right)$$

$$\frac{\partial P^M_{t+1}}{\partial b_t} \approx \sum_{j_b=0}^{n_b} \sum_{j_\epsilon=0}^{n_\epsilon} \frac{2\theta^{\widetilde{p}}_{j_b j_\epsilon}}{\left(b_{max} - b_{min}\right)(1-\rho\beta)} T'_{j_b}(\xi(b_i))T_{j_\epsilon}(\xi(\epsilon_j)) \equiv \widehat{P}^M_b\left(s'\right)$$

Hence, we can approximate the two partial derivatives under expectation

$$\frac{\partial E\left[M(s')\right]}{\partial b}$$

$$\approx \frac{1}{\sqrt{\pi}} \sum_{k=1}^{q} \omega_k \begin{bmatrix} -\sigma\left(\widehat{C}(s';\theta^c)\right)^{-\sigma-1} \widehat{Y}(s';\theta^y)\widehat{\Pi}(s';\theta^\pi)\left(\widehat{\Pi}(s';\theta^\pi)-1\right)\widehat{C}_b\left(s'\right) \\ +\left(\widehat{C}(s';\theta^c)\right)^{-\sigma} \widehat{\Pi}(s';\theta^\pi)\left(\widehat{\Pi}(s';\theta^\pi)-1\right)\widehat{Y}_b\left(s'\right) \\ +\left(\widehat{C}(s';\theta^c)\right)^{-\sigma} \widehat{\Pi}(s';\theta^\pi)\left(2\widehat{\Pi}(s';\theta^\pi)-1\right)\widehat{\Pi}_b\left(s'\right) \end{bmatrix}$$

$$\equiv \widehat{M}_b\left(s',q\right),$$

$$\frac{\partial E\left[L(s')\right]}{\partial b}$$

$$\approx \frac{1}{\sqrt{\pi}} \sum_{k=1}^{q} \omega_k \begin{bmatrix} -\sigma\left(\widehat{C}(s';\theta^c)\right)^{-\sigma-1}\left(\widehat{\Pi}(s';\theta^\pi)\right)^{-1}(1+\frac{\rho\widehat{P^M}\left(s';\theta^{\widetilde{p}}\right)}{1-\rho\beta})\widehat{C}_b\left(s'\right) \\ -\left(\widehat{C}(s';\theta^c)\right)^{-\sigma}\left(\widehat{\Pi}(s';\theta^\pi)\right)^{-2}(1+\frac{\rho\widehat{P^M}\left(s';\theta^{\widetilde{p}}\right)}{1-\rho\beta})\widehat{\Pi}_b\left(s'\right) \\ +\rho\left(\widehat{C}(s';\theta^c)\right)^{-\sigma}\left(\widehat{\Pi}(s';\theta^\pi)\right)^{-1}\widehat{P}^M_b\left(s'\right) \end{bmatrix}$$

$$\equiv \widehat{L}_b\left(s',q\right).$$

That is,

$$E\left[Z_b\left(X(s')\right)\right] \approx E\left[\widehat{Z}_b\left(X(s')\right)\right] = \begin{bmatrix} \widehat{M}_b\left(s',q\right) \\ \widehat{L}_b\left(s',q\right) \end{bmatrix}$$

4. At each collocation node s, solve for $X(s)$ such that

$$\Gamma\left(s, X(s), E\left[\widehat{Z}\left(X(s')\right)\right], E\left[\widehat{Z}_b\left(X(s')\right)\right]\right) = 0$$

The equation solver *csolve* written by Christopher A. Sims is employed to solve the resulted system of nonlinear equations. With $X(s)$ at hand, we can get the corresponding coefficient

$$\widehat{\Theta}^j_X = \left(\Omega\left(S\right)^T \Omega\left(S\right)\right)^{-1} \Omega\left(S\right)^T X(s)$$

5. Update the approximating coefficients, $\Theta_X^j = \eta\widehat{\Theta}_X^j + (1-\eta)\,\Theta_X^{j-1}$, where $0 \leq \eta \leq 1$ is some dampening parameter used for improving convergence.

6. Check the stopping rules. If $\left\|\Theta_X^j - \Theta_X^{j-1}\right\| < \epsilon_{tol}$, then stop, else update the approximation coefficients and go back to step 3.

When implementing the above algorithm, we start from lower order Chebyshev polynomials and some reasonable initial guess. Then, we increase the order of approximation and take as starting value the solution from the previous lower order approximation. This informal homotopy continuation idea facilitates obtaining the solution.

Remark. Given the fact that the price P_t^M fluctuates significantly for larger ρ, in numerical analysis, the rule for P_t^M is scaled by $(1-\rho\beta)$, that is, $\widetilde{P}_t^M = (1-\rho\beta)P_t^M$. In this way, the steady state of $\widetilde{P}_t^M$ is very close to β, and $\widetilde{P}_t^M$ does not differ hugely as we change the maturity structure.

F Euler Equation Errors

To assess the accuracy of solutions, we calculate the Euler equation errors on an evenly-spaced grid that consists of 40 points of b_t and 40 points of $log(\epsilon_t)$. The results are similar on a finer grid.

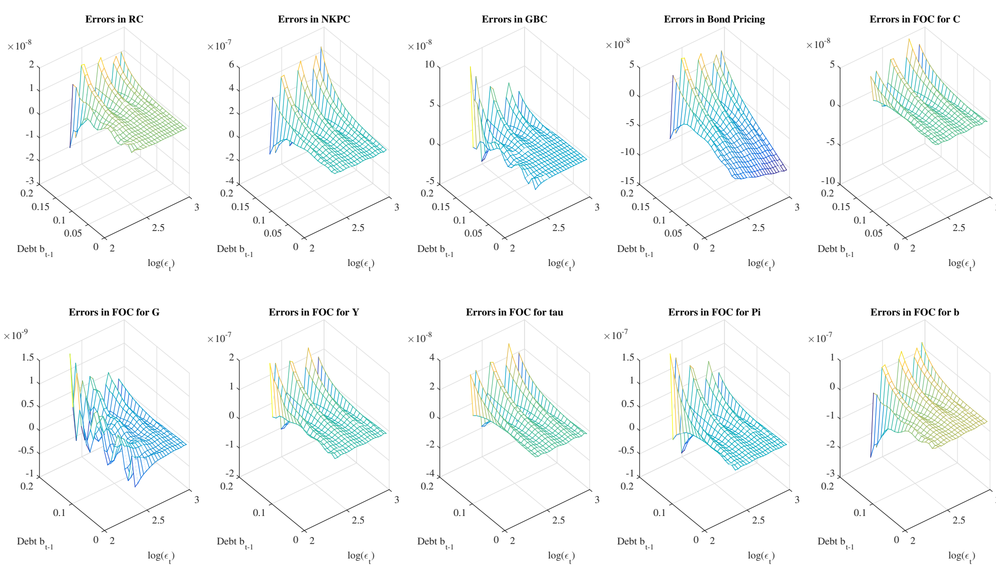

Figure 6: Euler equation errors in the state space used to the solve the benchmark model. This figure plots the Euler equation errors on an evenly-spaced grid. Euler equation errors for other model variants are available upon request.

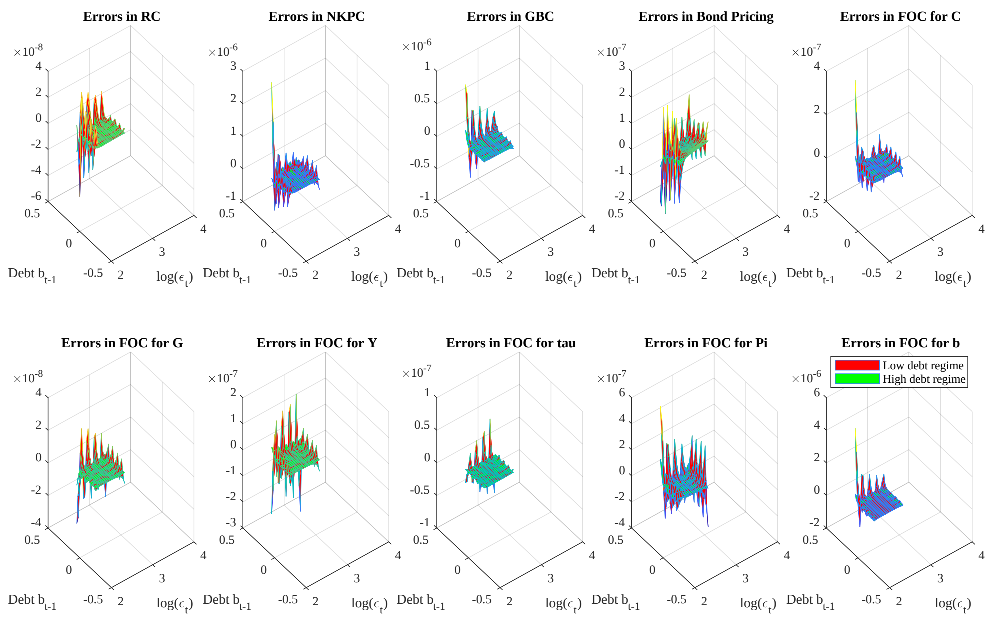

Figure 7: Euler equation errors in the state space used to the solve the benchmark model augmented with switching in the degree of policy maker myopia. This figure plots the Euler equation errors on an evenly-spaced grid. Euler equation errors for other model variants are available upon request.

G Model with Money

In this Section we introduce a monetary friction which has been used as a device to achieve a positive steady-state debt-to-GDP ratio in models similar to the model analyzed in our paper.

G.1 Households' Problem

The budget constraint at time t is given by

$$\int_0^1 P_t(j)C_t(j)dj(1+s(v_t)) + P_t^M B_t^M + M_t \leq \Xi_t + (1+\rho P_t^M)B_{t-1}^M + M_{t-1} + W_t N_t(1-\tau_t)$$

where $P_t(j)$ is the price of variety j , Ξ is the representative household's share of profits in the imperfectly competitive firms, W are wages, and τ is an wage income tax rate. Money, M_t, facilitates consumption purchases since consumption purchases are subject to a proportional transaction cost $s(v_t)$, which depends on consumption-based money velocity,

$$v_t = \frac{\int_0^1 P_t(j)C_t(j)dj}{M_{t-1}}$$

The transaction cost function satisfies the same assumptions as in Schmitt-Grohe and Uribe (2004b). Specifically, $s(v)$ satisfies:(i) $s(v)$ is non-negative and twice continuously differentiable; (ii)there is a satiation level of velocity, $\underline{v}$, such that $s(\underline{v}) = s'(\underline{v}) = 0$; (iii) $(v - \underline{v})s'(v) > 0$ for $v \neq \underline{v}$; and (iv)$2s'(v) + vs''(v) > 0$ for all $v \geq \underline{v}$. Note, however, following Niemann et al. (2013), that we have changed the timing assumption of Schmitt-Grohe and Uribe (2004b) to make this more akin to a cash in advance constraint. This ensures that unanticipated inflation is costly in the absence of sticky prices, just as anticipated inflation is.

As a result of introducing this transactions cost, the households' first order conditions become,

$$\beta R_t E_t \left\{ \frac{\mu_{t+1}}{\mu_t} \left(\frac{P_t}{P_{t+1}} \right) \right\} = 1 \tag{31}$$

where

$$\mu_t \equiv \frac{C_t^{-\sigma}}{(1 + s(v_t) + s'(v_t)v_t)}$$

and the declining payoff consols,

$$\beta E_t \left\{ \frac{\mu_{t+1}}{\mu_t} \left(\frac{P_t}{P_{t+1}} \right) \left(1 + \rho P_{t+1}^M\right) \right\} = P_t^M \tag{32}$$

Their second FOC relates to their demand for money,

$$1 = \beta E_t \left(\frac{\mu_{t+1}}{\mu_t} \right) \left(\frac{P_t}{P_{t+1}} \right) (1 + s'(v_{t+1})v_{t+1}^2)$$

The final FOC relates to their labour supply decision and is given by,

$$(1 - \tau_t) \left(\frac{W_t}{P_t} \right) = N_t^{\varphi} \mu_t^{-1}$$

That is, the marginal rate of substitution between consumption and leisure equals the after-tax wage rate.

G.2 Firms' Problem

The problem facing firms is the same as previously except the stochastic discount factor used to discount future profits is now given by, $Q_{t,t+1} = \beta \left(\frac{\mu_{t+1}}{\mu_t} \right) \Pi_{t+1}^{-1}$, such that the NKPC becomes,

$$\begin{aligned} 0 = & (1 - \epsilon) + \epsilon mc_t - \phi \Pi_t (\Pi_t - 1) \\ & + \phi \beta E_t \left[\left(\frac{\mu_{t+1}}{\mu_t} \right) \frac{Y_{t+1}}{Y_t} \Pi_{t+1} (\Pi_{t+1} - 1) \right] \end{aligned} \tag{33}$$

G.3 Market Clearing

Goods market clearing requires, for each good j,

$$Y_t(j) = C_t(j)(1 + s(v_t)) + G_t(j) + \eta_t(j)$$

which allows us to write,

$$Y_t = C_t(1 + s(v_t)) + G_t + \eta_t$$

with $\eta_t = \int_0^1 \eta_t(j)\, dj$. In a symmetrical equilibrium,

$$Y_t \left[1 - \frac{\phi}{2}(\Pi_t - 1)^2\right] = C_t(1 + s(v_t)) + G_t$$

G.4 The Government

The government's sequential budget constraint is adjusted to account for the seigniorage revenues,

$$P_t^M B_t^M + P_t^S B_t^S + M_t + \tau_t W_t N_t = P_t G_t + B_{t-1}^S + (1 + \rho P_t^M) B_{t-1}^M + M_{t-1}$$

which can be rewritten in real terms

$$P_t^M b_t + m_t = (1 + \rho P_t^M)\frac{b_{t-1}}{\Pi_t} + \frac{m_{t-1}}{\Pi_t} - \frac{W_t}{P_t} N_t \tau_t + G_t \tag{34}$$

where real debt is defined as, $b_t \equiv B_t^M / P_t$, and real money balances, $m_t = \frac{M_t}{P_t}$.

G.5 The Discretionary Policy Problem

The policy under discretion can be described as a set of decision rules for $\{C_t, Y_t, \Pi_t, b_t, \tau_t, G_t\}$ which maximize the following Lagrangian,

$$\begin{aligned}
\mathcal{L} = & \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} + \chi \frac{G_t^{1-\sigma_g}}{1-\sigma_g} - \frac{(Y_t)^{1+\varphi}}{1+\varphi} + \beta E_t[V(b_t, m_t, \epsilon_{t+1})] \right\} \\
& + \lambda_{1t} \left[Y_t \left(1 - \frac{\phi}{2}(\Pi_t - 1)^2\right) - C_t(1 + s(v_t)) - G_t \right] \\
& + \lambda_{2t} \left[\begin{array}{c} (1-\epsilon) + \epsilon(1-\tau_t)^{-1} Y_t^{\varphi} \mu_t^{-1} - \phi \Pi_t (\Pi_t - 1) \\ + \phi \beta \mu_t^{-1} Y_t^{-1} E_t [M(b_t, m_t, \epsilon_{t+1})] \end{array} \right] \\
& + \lambda_{3t} \left[\begin{array}{c} \beta b_t \mu_t^{-1} E_t [L(b_t, m_t, \epsilon_{t+1})] - \frac{b_{t-1}}{\Pi_t} \left(1 + \rho \beta \mu_t^{-1} E_t [L(b_t, m_t, \epsilon_{t+1})]\right) \\ + \left(\frac{\tau_t}{1-\tau_t}\right) (Y_t)^{1+\varphi} \mu_t^{-1} - G_t + m_t - \frac{m_{t-1}}{\Pi_t} \end{array} \right] \\
& + \lambda_{4t} \left[1 - \beta \mu_t^{-1} E_t N(b_t, m_t, \epsilon_{t+1})\right] \\
& + \lambda_{5t} \left[\mu_t - \frac{C_t^{-\sigma}}{(1 + s(v_t) + s'(v_t) v_t)} \right] \\
& + \lambda_{6t} [v_t - \frac{C_t \Pi_t}{m_{t-1}}]
\end{aligned} \tag{35}$$

where the auxiliary functions are defined as,

$$M(b_t, m_t, \epsilon_{t+1}) = \mu_{t+1} Y_{t+1} \Pi_{t+1} (\Pi_{t+1} - 1) \tag{36}$$

$$L(b_t, m_t, \epsilon_{t+1}) = \mu_{t+1} (\Pi_{t+1})^{-1} (1 + \rho P^M_{t+1}) \tag{37}$$

$$N(b_t, m_t, \epsilon_{t+1}) = \mu_{t+1} (\Pi_{t+1})^{-1} (1 + s'(v_{t+1}) (v_{t+1})^2) \tag{38}$$

We can write the first order conditions (FOCs) for the policy problem as follows:

The FOC for consumption,

$$\begin{aligned} C_t^{-\sigma} - \lambda_{1t} [1 + s(v_t)] - \lambda_{6t} \frac{v_t}{C_t} \\ + \lambda_{5t} \mu_t \sigma C_t^{-1} = 0 \end{aligned} \tag{39}$$

output,

$$\begin{aligned} -Y_t^{\varphi} + \lambda_{1t} \left[1 - \frac{\phi}{2} (\Pi_t - 1)^2 \right] \\ + \lambda_{2t} \left[\epsilon \varphi (1 - \tau_t)^{-1} Y_t^{\varphi - 1} \mu_t^{-1} - \phi \beta \mu_t^{-1} Y_t^{-2} E_t \left[M(b_t, m_t, \epsilon_{t+1}) \right] \right] \\ + \lambda_{3t} \left[(1 + \varphi) Y_t^{\varphi} \mu_t^{-1} \left(\frac{\tau_t}{1 - \tau_t} \right) \right] = 0 \end{aligned} \tag{40}$$

taxation,

$$\epsilon \lambda_{2t} + \lambda_{3t} Y_t = 0 \tag{41}$$

government consumption,

$$\chi G_t^{-\sigma_g} - \lambda_{1t} - \lambda_{3t} = 0 \tag{42}$$

inflation

$$\begin{aligned} -\lambda_{1t} [Y_t \phi (\Pi_t - 1)] - \lambda_{2t} [\phi (2\Pi_t - 1)] \\ + \lambda_{3t} \left[\frac{b_{t-1}}{\Pi_t^2} \left(1 + \rho \beta \mu_t^{-1} E_t \left[L(b_t, m_t, \epsilon_{t+1}) \right] \right) + \frac{m_{t-1}}{\Pi_t^2} \right] - \lambda_{6t} \frac{v_t}{\Pi_t} = 0 \end{aligned} \tag{43}$$

marginal utility, μ_t,

$$\begin{aligned} \lambda_{2t} \mu_t^{-2} [-\epsilon (1 - \tau_t)^{-1} Y_t^{\varphi} - \phi \beta Y_t^{-1} E_t \left[M(b_t, m_t, \epsilon_{t+1}) \right]] \\ + \lambda_{3t} \mu_t^{-2} [-\beta b_t E_t \left[L(b_t, m_t, \epsilon_{t+1}) \right] + \frac{b_{t-1}}{\Pi_t} \rho \beta E_t \left[L(b_t, m_t, \epsilon_{t+1}) \right] - \frac{\tau_t}{1 - \tau_t} (Y_t)^{1+\varphi}] \\ + \lambda_{4t} \left[\beta \mu_t^{-2} E_t \left[N(b_t, m_t, \epsilon_{t+1}) \right] \right] + \lambda_{5t} = 0 \end{aligned} \tag{44}$$

and velocity,

$$\begin{aligned} -\lambda_{1t} C_t s'(v_t) + \lambda_{6t} \\ + \lambda_{5t} \mu_t \left[\frac{(2s'(v_t) + s''(v_t) v_t)}{(1 + s(v_t) + s'(v_t) v_t)} \right] = 0 \end{aligned} \tag{45}$$

The remaining FOCs are for government debt,

$$0 = -\beta E_t \left[\frac{\lambda_{3t+1}}{\Pi_{t+1}} (1 + \rho P^m_{t+1}) \right] + \lambda_{2t} \left[\phi \beta \mu_t^{-1} Y_t^{-1} E_t \left[M_1(b_t, m_t, \epsilon_{t+1}) \right] \right]$$

$$+ \beta \lambda_{3t} \left[\mu_t^{-1} E_t \left[L(b_t, m_t \epsilon_{t+1}) \right] + b_t \mu_t^{-1} E_t \left[L_1(b_t, m_t, \epsilon_{t+1}) \right] - \rho \frac{b_{t-1}}{\Pi_t} \mu_t^{-1} E_t \left[L_1(b_t, m_t, \epsilon_{t+1}) \right] \right] \tag{46}$$

$$-\lambda_{4t} \left[\beta \mu_t^{-1} E_t \left[N_1(b_t, m_t, \epsilon_{t+1}) \right] \right]$$

and money balances,

$$\beta E_t[-\lambda_{3t+1} \frac{1}{\Pi_{t+1}} + \lambda_{6t+1} \frac{v_{t+1}}{m_t}]$$

$$+ \lambda_{2t} \left[\phi \beta \mu_t^{-1} Y_t^{-1} E_t \left[M_2(b_t, m_t, \epsilon_{t+1}) \right] \right]$$

$$+\beta \lambda_{3t} \left[\beta^{-1} + b_t \mu_t^{-1} E_t \left[L_2(b_t, m_t, \epsilon_{t+1}) \right] - \rho \frac{b_{t-1}}{\Pi_t} \mu_t^{-1} E_t \left[L_2(b_t, m_t, \epsilon_{t+1}) \right] \right]$$

$$- \lambda_{4t} \left[\beta \mu_t^{-1} E_t \left[N_2(b_t, m_t, \epsilon_{t+1}) \right] \right] = 0 \tag{47}$$

The discretionary equilibrium is determined by the system given by the FOCs, (39), - (47), the constraints in (35) , the auxiliary equations, (36)-(38), bond prices, $P_t^M = \beta C_t^\sigma E_t \left[L(b_t, \epsilon_{t+1}) \right]$, and the exogenous process for the markup shock,

$$\ln(\epsilon_t) = (1 - \rho_\epsilon) \ln(\bar{\epsilon}) + \rho_\epsilon \ln(\epsilon_{t-1}) + \sigma_\epsilon \varepsilon_t, \; \varepsilon_t \sim N(0, 1)$$

The solution to this system is a set of time-invariant Markov-perfect equilibrium policy rules $y_t = H(s_{t-1})$ mapping the vector of states $s_{t-1} = \{b_{t-1}, m_{t-1}, \epsilon_t\}$ to the optimal decisions for $y_t = \{C_t, G_t, Y_t, \Pi_t, \tau_t, b_t, m_t, P_t^M, \lambda_{1t}, \lambda_{2t}, \lambda_{3t}, \lambda_{4t}, \lambda_{5t}, \lambda_{6t}\}$ for all $t \geq 0$.

Solving this model can generate a positive steady-state debt-to-GDP ratio. However, it is only when price stickiness is reduced to implausibly low levels ($\phi < 4$, an effective average price duration of less than 4 months) that the debt-to-GDP ratio can be turned mildly positive. For example with $\phi = 2.5$ (equivalent to a Calvo probability of no price change of 0.14 and an average price duration of just under 3.5 months), the steady-state debt-to-GDP ratio is 13.3%, but this implies very large inflation response to shocks alongside negligible movements in the debt-to-GDP ratio. This suggests that the mild myopia adopted in this paper is a more data-consistent motivation for existence of a positive steady-state debt and the observed fluctuations in debt relative to that steady-state, which also facilitates a comparison with the commonly used cashless economy framework of much New Keynesian analysis of optimal policy.

H Switches in Policy Maker Myopia

In order to replicate the observed fluctuations in the debt-to-GDP ratio in the US, it is necessary to allow the degree of policy maker myopia to fluctuate between high and low levels, $\widetilde{\beta}_H$ and $\widetilde{\beta}_L$ as a two state Markov process with transition matrix, $\begin{bmatrix} p_H & 1 - p_H \\ 1 - p_L & p_L \end{bmatrix}$

where p_i is the probability of remaining in regime i, $i = H, L$ from the current period to the next. As a result of this change the policy problem is reformulated as,

$$\begin{aligned}
\mathcal{L} = & \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} + \chi \frac{G_t^{1-\sigma_g}}{1-\sigma_g} - \frac{(Y_t)^{1+\varphi}}{1+\varphi} + \widetilde{\beta}_{i,t} E_t [V(b_t, \epsilon_{t+1}, \widetilde{\beta}_{i,t+1})] \right\} \\
& + \lambda_{1t} \left[Y_t \left(1 - \frac{\phi}{2} (\Pi_t - 1)^2 \right) - C_t - G_t \right] \\
& + \lambda_{2t} \left[\begin{array}{c} (1-\epsilon_t) + \epsilon_t (1-\tau_t)^{-1} Y_t^{\varphi} C_t^{\sigma} - \phi \Pi_t (\Pi_t - 1) \\ + \phi \beta C_t^{\sigma} Y_t^{-1} E_t \left[M(b_t, \epsilon_{t+1}, \widetilde{\beta}_{i,t+1}) \right] \end{array} \right] \\
& + \lambda_{3t} \left[\begin{array}{c} \beta b_t C_t^{\sigma} E_t \left[L(b_t, \epsilon_{t+1}, \widetilde{\beta}_{i,t+1}) \right] - \frac{b_{t-1}}{\Pi_t} \left(1 + \rho \beta C_t^{\sigma} E_t \left[L(b_t, \epsilon_{t+1}, \widetilde{\beta}_{i,t+1}) \right] \right) \\ + \left(\frac{\tau_t}{1-\tau_t} \right) (Y_t)^{1+\varphi} C_t^{\sigma} - G_t - tr \end{array} \right]
\end{aligned} \tag{48}$$

The policy maker optimizes this Lagrangian by choosing C_t, G_t, Y_t, Π_t, τ_t, b_t and the multipliers, λ_{1t}, λ_{2t}, λ_{3t}. The only difference between these FOCs and those in the benchmark model are that the FOC for debt now depends upon the myopia of the current policy maker, $\widetilde{\beta}_{i,t}$, such that

$$\underbrace{P_t^M \lambda_{3t} - \widetilde{\beta}_{i,t} E_t \left[\frac{\lambda_{3t+1}}{\Pi_{t+1}} (1 + \rho P_{t+1}^M) \right]}_{\text{tax smoothing}}$$

$$\underbrace{-\lambda_{3t} C_t^{\sigma} \left(\phi \epsilon^{-1} \beta E_t \left[M_1(b_t, \epsilon_{t+1}, \widetilde{\beta}_{i,t+1}) \right] - \left[(b_t - \rho \frac{b_{t-1}}{\Pi_t}) E_t L_1(b_t, \epsilon_{t+1}, \widetilde{\beta}_{i,t+1}) \right] \right)}_{\text{debt stabilization bias}} = 0 \tag{49}$$

The solution to the resultant system of FOCs is a set of time-invariant Markov-perfect equilibrium policy rules $y_t = H(s_{t-1})$ mapping the vector of states $s_{t-1} = \{b_{t-1}, \epsilon_t, \widetilde{\beta}_{i,t}\}$ to the optimal decisions for $y_t = \{C_t, G_t, Y_t, \Pi_t, \tau_t, b_t, P_t^M, \lambda_{1t}, \lambda_{2t}, \lambda_{3t}\}$ for all $t \geq 0$. In formulating the policy problem in this way the policy maker does not try to tie the hands of their future selves. They simply accept that there are periods in which they will be relatively more or less patient. To allow for conflict between two policy makers of different degrees of myopia, it would be necessary for each policy maker to evaluate the anticipated policy outcomes when their opponent was in power using their own discount factor and adjust policies in influence their opponent's behavior. It would be interesting to consider these strategic interactions in future work.

I Optimal Policy Under Discretion With Endogenous Short-Term Debt

The Lagrangian for the policy problem can be written as,

$$\mathcal{L} = \left\{ \frac{C_t^{1-\sigma}}{1-\sigma} + \chi \frac{G_t^{1-\sigma_g}}{1-\sigma_g} - \frac{(Y_t)^{1+\varphi}}{1+\varphi} + \beta E_t[V(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S)] \right\}$$
$$+ \lambda_{1t} \left[Y_t \left(1 - \frac{\phi}{2} (\Pi_t - 1)^2 \right) - C_t - G_t \right]$$
$$+ \lambda_{2t} \left[\begin{array}{c} (1-\epsilon_t) + \epsilon_t (1-\tau_t)^{-1} Y_t^{\varphi} C_t^{\sigma} - \phi \Pi_t (\Pi_t - 1) \\ + \phi \beta C_t^{\sigma} Y_t^{-1} E_t \left[M(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S) \right] \end{array} \right]$$
$$+ \lambda_{3t} \left[\begin{array}{c} \beta b_t C_t^{\sigma} E_t \left[L(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S) \right] + \beta b_t^S C_t^{\sigma} E_t \left[K \left(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S \right) \right] \\ - \frac{b_{t-1}}{\Pi_t} \left(1 + \rho \beta C_t^{\sigma} E_t \left[L(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S) \right] \right) \\ - \frac{b_{t-1}^S}{\Pi_t} + \left(\frac{\tau_t}{1-\tau_t} \right) (Y_t)^{1+\varphi} C_t^{\sigma} - G_t - tr \end{array} \right]$$

where

$$M(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it}, b_t^S) = (C_{t+1})^{-\sigma} Y_{t+1} \Pi_{t+1} (\Pi_{t+1} - 1)$$
$$L(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it}, b_t^S) = (C_{t+1})^{-\sigma} (\Pi_{t+1})^{-1} (1 + \rho P_{t+1}^M)$$
$$K \left(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it}, b_t^S \right) = C_{t+1}^{-\sigma} \Pi_{t+1}^{-1}$$

We can write the first order conditions for the policy problem as follows: consumption,

$$C_t^{-\sigma} - \lambda_{1t} + \lambda_{2t} \left[\sigma \epsilon (1-\tau_t)^{-1} Y_t^{\varphi} C_t^{\sigma-1} + \sigma \phi \beta C_t^{\sigma-1} Y_t^{-1} E_t \left[M(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S) \right] \right]$$
$$+ \lambda_{3t} \left[\begin{array}{c} \sigma \beta b_t C_t^{\sigma-1} E_t \left[L(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S) \right] + \sigma \beta b_t^S C_t^{\sigma-1} E_t \left[K \left(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S \right) \right] \\ - \rho \sigma \beta \frac{b_{t-1}}{\Pi_t} C_t^{\sigma-1} E_t \left[L(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S) \right] + \sigma \left(\frac{\tau_t}{1-\tau_t} \right) (Y_t)^{1+\varphi} C_t^{\sigma-1} \end{array} \right] = 0$$

government spending,

$$\chi G_t^{-\sigma_g} - \lambda_{1t} - \lambda_{3t} = 0$$

output,

$$-Y_t^{\varphi} + \lambda_{1t} \left[1 - \frac{\phi}{2} (\Pi_t - 1)^2 \right]$$
$$+ \lambda_{2t} \left[\epsilon \varphi (1-\tau_t)^{-1} Y_t^{\varphi-1} C_t^{\sigma} - \phi \beta C_t^{\sigma} Y_t^{-2} E_t \left[M(b_t, \epsilon_{t+1}, \widetilde{\beta}_{it+1}, b_t^S) \right] \right]$$
$$+ \lambda_{3t} \left[(1+\varphi) Y_t^{\varphi} C_t^{\sigma} \left(\frac{\tau_t}{1-\tau_t} \right) \right] = 0$$

taxation,

$$\epsilon \lambda_{2t} + \lambda_{3t} Y_t = 0$$

inflation,

$$-\lambda_{1t} [Y_t \phi (\Pi_t - 1)] - \lambda_{2t} [\phi (2\Pi_t - 1)]$$

$$+\lambda_{3t}\left[\frac{b_{t-1}}{\Pi_t^2}\left(1+\rho\beta C_t^\sigma E_t\left[L(b_t,\epsilon_{t+1},b_t^S)\right]\right)+\frac{b_{t-1}^S}{\Pi_t^2}\right]=0$$

and the FOCs for government debt b_t and b_t^S, respectively,

$$-\widetilde{\beta}_{i,t}E_t\left[\frac{\lambda_{3t+1}}{\Pi_{t+1}}(1+\rho P_{t+1}^M)\right]+\lambda_{2t}\phi\beta C_t^\sigma Y_t^{-1}E_t\left[M_1(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S)\right]$$

$$+\beta C_t^\sigma\lambda_{3t}\left[\begin{array}{c} E_t\left[L(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S)\right]+b_tE_t\left[L_1(b_t,\epsilon_{t+1},b_t^S)\right]+b_t^SE_t\left[K_1\left(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S\right)\right] \\ -\rho\frac{b_{t-1}}{\Pi_t}E_t\left[L_1(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S)\right]\end{array}\right]=0$$

and

$$-\widetilde{\beta}_{i,t}E_t[\frac{\lambda_{3t+1}}{\Pi_{t+1}}]+\lambda_{2t}\phi\beta C_t^\sigma Y_t^{-1}E_t\left[M_3(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S)\right]$$

$$+\beta C_t^\sigma\lambda_{3t}\left[\begin{array}{c} b_tE_t\left[L_3(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S)\right]+E_t\left[K\left(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S\right)\right]+b_t^SE_t\left[K_3\left(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S\right)\right] \\ -\rho\frac{b_{t-1}}{\Pi_t}E_t\left[L_3(b_t,\epsilon_{t+1},\widetilde{\beta}_{it+1},b_t^S)\right]\end{array}\right]=0$$

J Lower Intertemporal Elasticity of Substitution for Government Consumption

This section recreates Figure 4, but reduces the inverse of the elasticity of substitution for government consumption in utility to $\sigma_g = 1$. This increases the use of government consumption as a fiscal policy instrument, but without changing any of the conclusions of the main paper. See Figure 8 below.

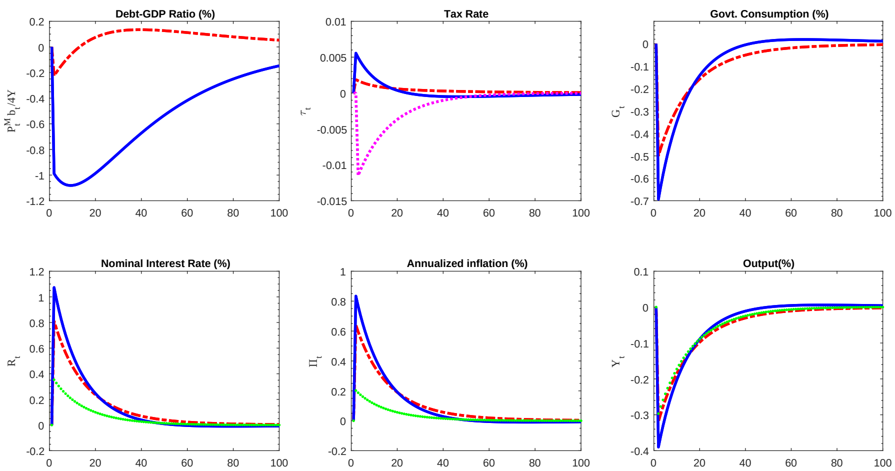

Figure 8: Impulse Response to Mark-Up Shock under High/Low Debt Regimes: Robustness Check. Government consumption and output measured as percentage deviation from steady-state. All other variations as deviation from steady-state. New Keynesian model without fiscal policy - green dotted line. Hypothetical tax rate which would offset shock - dotted magenta line. Monetary and fiscal response under high myopia/debt regime - blue solid line. Monetary and fiscal response under low myopia/debt regime - red dot-dash line.

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