# Optimal Debt Policy and Liquidity Taxation

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**Abstract**

Does the U.S. have too much public debt? Some worry that high levels are unsustainable, yet strong investor demand for liquidity keeps interest rates low. Public debt's liquidity services are so valuable that the government's borrowing rate $r$ is less than the growth rate $g$. The tax base grows faster than interest payments. Since $r < g$, policymakers can sustain primary deficits without fiscal adjustment. However, keeping interest rates low deprives markets of valuable liquidity. There is a trade-off between labor and liquidity taxation. To quantify the importance of this trade-off, I solve for the optimal Ramsey policy of a government that issues safe assets (i.e., risk-free and liquid), taxes labor, and insures against aggregate risk. Introducing quantitatively realistic liquidity demand into an otherwise standard optimal debt model dampens policymakers' tax-smoothing and precautionary savings motives. Calibrating my quantitative model to U.S. data, I find that recent crises were overly debt-financed. While debt expansion was the optimal response to these crises, primary deficits were too high. The over-reliance on debt financing pushed the debt-to-GDP ratio 10 p.p. above optimum. Given the projected path of government expenditure, the model suggests that, over the next 10 years, policymakers should reduce the debt to 75% of GDP. In extensions of the baseline model, I consider the optimal debt policy during liquidity and default crises.

**Keywords:** fiscal policy, debt sustainability, optimal taxation, liquidity tax, convenience yields
**JEL:** E43, E61, E62, E63, H21, H62, H63

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# 1 Introduction

Public debt in the United States has been elevated and growing for some time. From 1980 to 2020 total public debt grew from 30% to 100% of GDP. Aggressive policy reactions to the COVID-19 pandemic brought public debt to levels not reached since World War II. Elevating public debt from 107% to 135% of GDP over this period pushed interest payments from 2.5% to 3.6% of GDP. A Congressional Budget Office report notes that "high and rising federal debt makes the economy more vulnerable to rising interest rates and, depending on how that debt is financed, rising inflation." (*Options for Reducing the Deficit: 2021 to 2030* (2020)). Politicians, policymakers, investors, and academics alike worry that paying down the public debt requires substantial tax increases. Given these concerns does the U.S. have too much public debt?

Standard optimal debt models suggest U.S. public debt levels are well above the optimal level (Aiyagari et al. (2002) and Bhandari et al. (2017a)). These models recommend debt levels at or below zero. Since the government is constrained by an intertemporal budget, current and future distortionary labor taxes fund current public debt. Negative optimal debt levels emerge from the government's desire to smooth and lower future labor taxes. By amassing a "war-chest" of assets, i.e., negative debt, policymakers use precautionary and buffer stock savings to insure against future tax increases. Intuitively, today's debts are tomorrow's taxes.

The high public debt levels and low interest rates in the United States are inconsistent with these models of optimal debt issuance (Yared (2019)). Standard models predict that public debt expansions raise interest rates. Yet as public debt levels rose dramatically over the previous fifty years interest rates on Treasury bonds fell. Throughout this period, the real interest rate $r$ generally remained below the growth rate $g$ (Blanchard (2019)). Because tax-base growth outpaces interest payments on the debt, that is $r < g$, the U.S. avoids fiscal adjustment. Despite recent interest rate hikes, this interest-growth rate differential is likely to persist (Arslanalp and Eichengreen (2023)). In his provocative address Blanchard (2019) argues that additional U.S. debt may have "no fiscal cost."

Introducing liquidity demand to standard debt models reconciles the observed high debt levels and low interest rates. The United States can sell public debt at low interest rates because holders of Treasury bonds are partially compensated by liquidity services. Public debt provides liquidity by uniquely facilitating trade – during crises (Woodford (1990) and Holmström and Tirole (1998)), between borrowing-constrained households (Aiyagari and McGrattan (1998) and Brunnermeier et al. (2022)) and across generations (Diamond (1965) and Blanchard (2019)). Treasury bonds are more liquid than similarly safe private bonds (Krishnamurthy and Vissing-Jorgensen (2012)) and sovereign debt (Du et al. (2018)). Recent work (e.g. Blanchard (2019), Mehrotra and Sergeyev (2021), Mian et al. (2022), Brunnermeier et al. (2022), and Kocherlakota (2023)) demonstrates that empirically plausible liquidity demand can sustain high public debt levels and low interest rates in the United States.

Does empirically plausible liquidity demand suggest that current debt levels are optimal? Just because policymakers can sustain debt, does not mean they should. On the one hand, low interest rates on public debt present the opportunity to run primary deficits indefinitely at high debt levels[1].

[1] Brunnermeier et al. (2022) refer to this policy as "mining the bubble." Since the value of government debt is

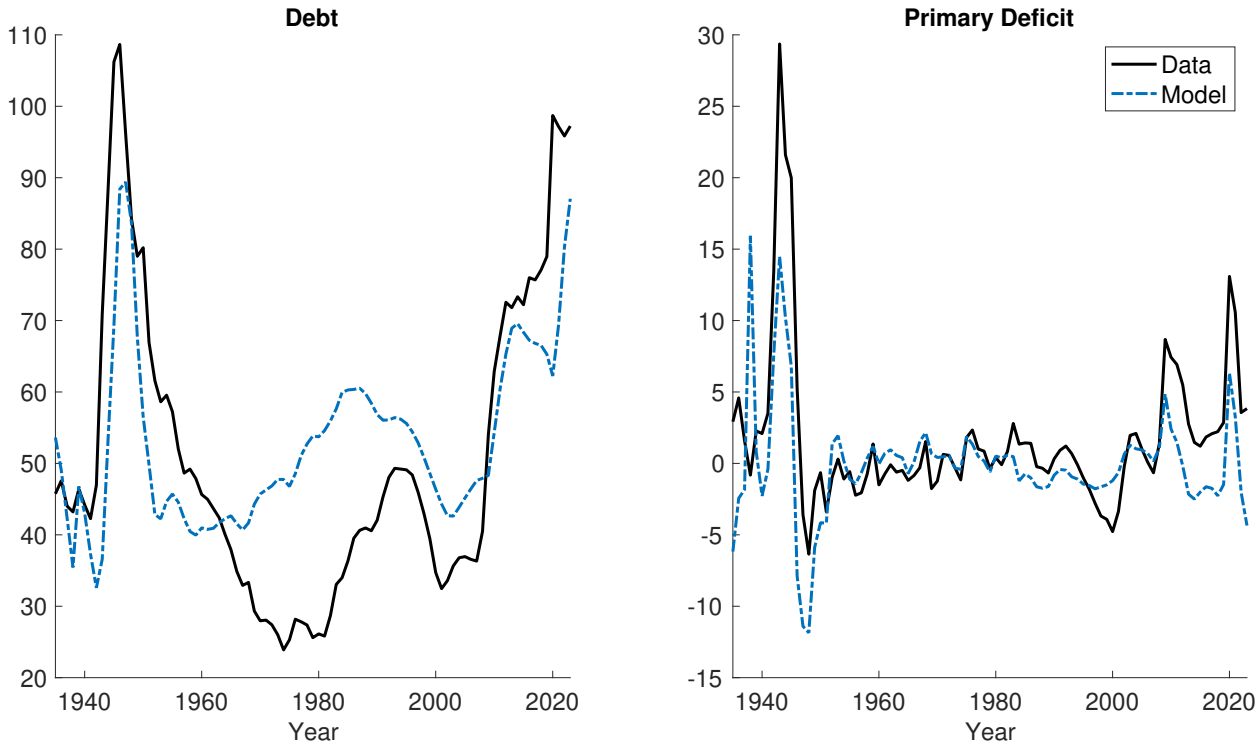



Figure 1: **Historical debt and primary deficit ratios.** This figure plots the actual and optimal debt and primary deficit ratios in the United States since 1935. Actual debt is the gross debt held by the public (FYGFDPUB in FRED). Optimal policy begins in 1935 with the same debt and expenditure level as the actual history.

Policymakers can lower taxes and pay for government expenditure with inexpensive public debt. On the other hand, for this policy to be sustainable there must be enough fiscal space to insure against surplus and interest rate risk. A surprise increase in government spending – due to a financial crisis, epidemic, or war – would stress the U.S. budget. A sudden rise in interest rates could necessitate fiscal consolidation.

To quantify the impact of liquidity demand on optimal debt policy I consider a quantitative model with empirically plausible fiscal risk and liquidity demand. Specifically I solve for the optimal Ramsey policy in a calibrated model with liquidity demand, distortionary labor taxes, and surplus risk. In my model the government levies labor taxes and issues safe – i.e. risk-free and liquid – public debt to cover surprise expenditure. The government raises revenue by either taxing labor or liquidity. The policymaker taxes liquidity by undersupplying public debt to suppress interest rates. Just as inflation is a tax on money's liquidity (Friedman (1971)), interest rate reduction is a tax on public debt's liquidity. I introduce fiscal risk separately as surplus risk and interest rate risk. Following the literature (e.g. Lucas and Stokey (1983), Angeletos et al. (2023), and Bhandari et al. (2017a)) I introduce surplus risk through uninsurable exogenous shocks to government expenditure. While surplus risk increases the cost of raising revenue, interest rate and default risks increases the cost of repayment. In extensions, I introduce interest rate risk with liquidity shocks

above it's fundamental value there is a bubble on U.S. public debt (Brunnermeier et al. (2022) and Jiang et al. (2019)). Policymakers "mine" this bubble to fund tax cuts.

and default risk with strategic default.

Calibrating my model to the United States, I find that liquidity is overtaxed during peacetime and debt is overused during crises. As a preview of the results, figure 1 plots the actual and model implied debt and primary deficits (as percentages of GDP) in the United States since 1935. In the model and the data, policymakers partially debt-finance wars and crises. According to the model, U.S. policymakers relied too heavily on debt to pay for these episodes. Debt reliance lead debt ratios to be 10-20% higher than optimal during crises. The model also shows that policymakers overtax liquidity during peacetime. The optimal debt target during peacetime is 40-70% of GDP – higher than actual midcentury policy. By undersupplying debt, U.S. policymakers deprived markets of liquidity and kept interest rates too low. Given current projections of government expenditure, the model recommends reducing the debt ratio to 75% over the next 10 years. This will require substantial primary surpluses, antithetical to the projected primary deficits (*The Budget and Economic Outlook: 2024 to 2034* (2020)). Historically the U.S. overtaxes liquidity during peacetime and undertaxes labor during crises. Going forward, the model recommends reducing the debt.

This quantitative debt model produces ergodic distributions for optimal debt, labor taxes, liquidity taxes, and interest rates. While the optimal debt ratio target is 70%, there is always a potential debt-financed crisis. So, policymakers are unlikely to reach this target. The average optimal debt ratio across many stochastic expenditure realizations is 125%. This average debt ratio is high compared to the previous literature (0%-60%), similar compared to current levels (100%), and small compared to the theoretical debt limit (270%). Optimal labor taxes are higher and more volatile than earlier work and current levels. Optimal deficits are near zero during peacetime and 5-15% during crises. Optimal interest rate suppression is significantly lower than the historical average.

Introducing household liquidity demand to optimal debt models overturns two standard findings: labor tax smoothing and negative optimal debt. First, even with complete markets perfect labor tax smoothing is suboptimal if households demand liquidity. Instead policymakers aim to simultaneously smooth labor *and* liquidity taxes. The policy goal of smoothing liquidity taxes, absent from complete markets models (e.g. Lucas and Stokey (1983)), leads policymakers to depart from standard optimal policy by partially distorting labor taxes. The relative value of smoothing labor or liquidity taxes depends on the relative magnitudes of the Frisch elasticity and the liquidity demand parameters. Even with moderate liquidity demand, optimal policy deviates from perfect labor tax smoothing. Second, with incomplete debt markets positive debt is optimal. Normally in an incomplete markets model the policymaker amasses assets as a form of precautionary and buffer stock savings. Policymakers use this asset position to pay for government expenditure and keep labor taxes low. In my model, policymakers amass *debt* to supply households with liquidity. In contrast to incomplete markets models (e.g. Aiyagari et al. (2002) and Bhandari et al. (2017a)), positive debt levels are optimal even with moderate liquidity demand. The relative value of saving assets or satiating liquidity depends on the relative magnitude of the intertemporal elasticity of substitution to the liquidity demand parameters.

Moving beyond surplus risk, I consider the optimal policy response to a liquidity crisis. The Great Depression, Volcker Disinflation, and Great Financial Crisis all featured a sudden rise in the demand for liquidity. The model recommends policymakers expand public debt in response to

these kinds of liquidity crises. In an extension of the baseline model, I solve for the optimal Ramsey policy given stochastic liquidity demand. I calibrate this quantitative model to match the historical fluctuations in Treasury's liquidity premium. Faced with a liquidity crisis, expanding the debt is optimal. But debt expansion should only partially satiate surprise liquidity demand. The remaining liquidity demand should be channeled toward reducing interest rates and labor taxes. This policy echoes Sims (2024) findings in a perfect foresight model. Relatedly, Kocherlakota (2023) finds that liquidity risk can help sustain more public debt: the chance of a future demand spike reduces borrowing costs today. I find that U.S. policymakers can and *should* sustain more public debt to partially insure against future liquidity crises. Policymakers must carry enough public debt to ensure markets can access sufficient liquidity when needed. But policymakers should only partially satiate this demand and channel the rest toward lower interest rates and labor taxes.

Readers may worry that the elevated debt levels prescribed by the baseline model are unsustainable. At some point, policymakers will default rather than repay. Greece's debt crisis began when their debt ratio was just over 100%. Is the United States at risk of default at the current debt ratio? To answer this question, I solve for the optimal debt policy in an extension of the baseline model with strategic default. Using this model, I show that optimal debt policy in economies with liquidity demand is robust to default risk. As in Eaton and Gersovitz (1981)'s seminal paper, policymakers optimally default in this extension. Defaulting allows policymakers to reduce the debt burden and labor taxes. However, default produces a protracted recession during which policymakers are barred from debt markets. If households demand liquidity, default also induces a costly liquidity crisis. In a quantitative model calibrated to match liquidity demand and empirical default costs, I demonstrate that optimal debt policy is little affected by the possibility of default. The United States would only default if the debt ratio exceeded 400%.

## 1.1 Related Work

This paper contributes to the debt management literature. In pioneering work, Barro (1979) found that policymakers managing the debt should smooth taxes. When markets are complete, Lucas and Stokey (1983) find that policymakers can perfectly insure households against labor tax fluctuations. I extend this literature by demonstrating that even with complete markets policymakers desire to smooth liquidity taxes leads to volatile labor taxes. The central finding of Aiyagari et al. (2002) and Bhandari et al. (2017a) is that without complete markets policymakers cannot insure against tax fluctuations. Faced with this impossibility, policymakers build up a large asset position to insure against fiscal risk and reduce labor taxes. I overturn this result, demonstrating that for reasonable liquidity demand a positive debt level is optimal.

This paper also contributes to the liquid debt literature. Private debt cannot provide the safety and liquidity of public debt . Public debt is uniquely valuable due to its singular ability to insure against aggregate and idiosyncratic shocks. While financial intermediaries can utilize credit lines to provide firms with insurance against idiosyncratic shocks, they are unable to insure against aggregate shocks like recessions, wars, and financial crises (Holmström and Tirole (1998) and Azzimonti and Yared (2019)). Because governments can borrow against the future by pledging future tax increases public debt can uniquely insure against aggregate shocks. Public debt provides liquidity in heterogeneous agent models (a la Woodford (1990), Aiyagari and McGrattan (1998), Brun-

nermeier et al. (2022)) by allowing households to partially insure themselves against uninsurable idiosyncratic risk through savings and risk-sharing. A more recent literature (e.g. Bayas-Erazo (2023), LeGrand and Ragot (2023)) analyzes optimal debt policy with heterogeneous agents and aggregate shocks. Solving for optimal policies in these environments is difficult, therefore these papers have not considered fiscal risk and fiscal space. I extend this literature by considering both liquidity provision and fiscal space. While public debt provides safety and liquidity services, debt sustainability concerns restrict policymakers from completely satiating liquidity demand.

This paper additionally contributes to the low interest rate literature. Recent papers discussing the policy implications of low interest rates on public debt include Barro (2022), Mankiw (2022), Reis (2021), Kocherlakota (2022), Mian et al. (2022), Brunnermeier et al. (2022), Bayas-Erazo (2023), Choi et al. (2024), Mehrotra and Sergeyev (2021), Angeletos et al. (2023), de Lannoy et al. (2022), and Sims (2024). The latter three are the most connected to my paper. Angeletos et al. (2023) considers the optimal response of labor taxes and public debt to unexpected shocks in an economy with liquidity demand. They find that labor taxes should be front loaded to keep deficits initially lower and allow the government to earn "seignorage" on the debt through liquidity taxation. My paper also finds that labor taxes should initially absorb expenditure shocks, though the incentive to earn debt "seignorage" is much weaker. Moreover, I consider the optimal level of debt under uncertainty rather than with perfect foresight. Additionally, I calibrate a quantitative model to U.S. data while Angeletos et al. (2023) focus on the theoretical forces that dictate the optimal level of debt. de Lannoy et al. (2022) consider the optimal maturity structure of public debt in an economy with liquidity demand. In contrast, I quantify the optimal level of debt rather than the maturity structure at a given level. Finally, Sims (2024) considers optimal liquidity provision and labor taxation in a model with perfect foresight and finds that a small liquidity tax is optimal. With quantitatively realistic fiscal risk I find that a moderate liquidity tax is optimal.

This paper finally contributes to the sovereign default literature. Pouzo and Presno (2022) consider optimal taxation in a closed economy model of risk neutral households with noncontingent debt and strategic default. Introducing default radically lowers optimal debt levels (Sec 5, pg 20). My model shares a similar market structure but focuses on risk averse households that demand liquidity. Default is less beneficial in my economy because the government only partially, rather than fully, defaults. Absent liquidity demand I also find that the option to default reduces optimum debt. With liquidity demand the debt reduction is minor. D'Erasmo and Mendoza (2021) explore optimal sovereign default in an open economy Bewley model. Debt issuance provides domestic households with liquidity. These households use public debt to self-insure against idiosyncratic risk. Similarly to my paper these authors find that the liquidity crisis induced by sovereign default is quite costly. However they do not consider optimal taxation since taxes are assumed to be constant. Similarly to this paper, Mehrotra and Sergeyev (2021) consider the sustainability of public debt given its non-pecuniary value. Differently from this paper, the authors impose a fiscal rule and discuss the conditions for sustainability, whereas I solve for optimal policy. Moreover, the government in my model must resort to distortionary labor taxes, rather than lump-sum taxes as in Mehrotra and Sergeyev (2021).

## 1.2 Layout

The rest of the paper is organized as follows. Section 2 lays out the baseline model. Section 3 characterizes optimal policy for a government that issues state-contingent bonds. Section 4 characterizes optimal policy for a government that issues noncontingent bonds. Section 5 presents an extension of the baseline model with liquidity shocks. Section 6 considers a model with strategic default. Section 7 concludes.

# 2 Baseline Model

In this section, I layout a dynamic stochastic general equilibrium model featuring liquidity demand, distortionary taxes, and surplus risk. Namely the government must finance a stochastic stream of exogenous expenditure shocks through distortionary labor taxes and debt issuance given that the household demands liquidity. This baseline model facilitates comparison to other standard domestic debt models. The models of Lucas and Stokey (1983) and Bhandari et al. (2017a) are limiting cases of my model in which there is no liquidity demand. Before discussing optimal policy in Sections 3 and 4, I discuss how I calibrate this model and compute the equilibrium.

The economy consists of three agents: a representative firm, a representative household, and the government. After describing the nature of stochastic shocks I spell out the preferences and objectives for each.

## 2.1 States of Nature

Time is discrete and indexed by $t = 0, 1, 2, ....$ The state $s_t \in \mathbb{S}$ summarizes the exogenous stochastic disturbances in year $t$. The possible set of states $\mathbb{S}$ is finite with size $S$. I denote the history of states $s_t$ up to and including year $t$ by $s^t = s_0, s_1, ..., s_{t-1}, s_t \in \mathbb{S}^t$. The unconditional probability of history $s^t$ at time $t$ is $\Omega_t(s^t)$. These states $s_t$ follow a Markov process which evolve according to transition probability matrix $\Omega(s'|s) = Pr[s_{t+1} = s'|s_t = s]$. For ease of notation, let $Z_t$ denote the realization of an arbitrary variable $Z$ in time $t$ for history $s^t$; for example, consumption in year $t$ given history $s^t$ is $C_t = C_t(s^t)$.

For most of the paper the state $s^t$ is isomorphic to the government expenditure level $G_t = G(s^t)$. In an extension of the model in Section 5, the state $s^t$ is isomorphic to the exogenous liquidity demand level $\nu_t = \nu(s^t)$.

## 2.2 Firm

The firm employs labor $N_t$ at real wage rate $W_t$ and produces output $Y_t$ using the production technology $F(N_t)$. Labor is the sole factor of production. This production is linear in labor supply $F(N_t) = N_t$. Profit maximization by the firm implies that the wage rate $W_t$ is unity each year. There are zero profits for all states $s^t$ and times $t$.

## 2.3 Household

First, I explain how household liquidity demand is modeled. Second, I present households preferences and subsequent optimization conditions.

### 2.3.1 Liquidity Demand

In my model, liquidity demand is represented by bonds-in-the-utility function. Depicting the demand for government debt's liquidity as bonds-in-the-utility function harkens back to Sidrauski (1967)'s depiction of the demand for money's liquidity with money-in-the-utility function. Both represent the excess demand for money and bonds beyond their function as a savings technology. Just as money-in-the-utility function allows tractable analysis of optimal monetary policy (e.g. Chari and Kehoe (1999)), bonds-in-the-utility function allows tractable analysis of optimal fiscal policy (e.g. Angeletos et al. (2023)). Specifically, optimal fiscal policy in an environment with aggregate risk. A voluminous literature, including Woodford (1990), Holmström and Tirole (1998), Aiyagari and McGrattan (1998), Blanchard (2019), Azzimonti and Yared (2019), and Brunnermeier et al. (2022), explores why firms and households have a particular demand for public debt over other kinds of private debt[2]. Recently, Gaillard et al. (2023) found that bonds-in-the-utility function is necessary in an Aiyagari (1994) model to match the joint distributions of consumption, wealth and capital income.

Let $b$ be the debt-to-output ratio. Henceforth, I refer to this as the debt ratio. The bonds-in-the-utility functional form,

$$w(b) = \begin{cases} (\nu+\phi)b - \phi b \sinh^{-1}(b) & b < b^{liq.sat.} \\ f(\nu+\phi)b^{liq.sat.} - \phi b^{liq.sat.} \sinh^{-1}(b^{liq.sat.}) & b \geq b^{liq.sat.} \end{cases}. \tag{1}$$

I use to represent liquidity demand closely matches empirical estimates. The utility of liquidity $w(b)$ is concave. The marginal utility of liquidity $w_b(b) = \nu - \phi \sinh^{-1}(b)$, for $b < b^{liq.sat.}$ is monotonically decreasing and equals zero when $b \geq b^{liq.sat.}$. $b^{liq.sat.}$ is the liquidity satiating debt ratio beyond which government debt provides no additional liquidity services. The liquidity satiating debt ratio is defined implicitly as the level at which the marginal utility of debt is zero $w_b(b_t^{liq.sat.}) = 0$ and explicitly as $b_t^{liq.sat.} = .5\exp\left(\frac{\nu}{\phi}\right) - .5\exp\left(-\frac{\nu}{\phi}\right)$.

[2]Money-in-the-utility function can be micro-founded with shopping-time models (e.g. McCallum (1983)) or cash-in-advance models (Bohn (1991)). Bonds-in-the-utility can similarly be microfounded by emphasizing public debt's role as a tradeable asset (Woodford (1990)) or by emphasizing its role in relaxing collateral constraints (Holmström and Tirole (1998)). Aggregating the welfare of heterogeneous agents facing uninsurable idiosyncratic risk, as in Brunnermeier et al. (2022), produces bonds-in-the-utiltiy function in the representative welfare function. Angeletos et al. (2023) directly microfounds bonds-in-the-utility function using Woodford (1990), Holmström and Tirole (1998) and Aiyagari and McGrattan (1998). The addition of bonds-in-the-utility function to a representative agent concisely captures the liquidity services public debt provides to households facing uninsurable idiosyncratic risk. Adding bonds-in-the-utility function to a representative agent New Keynesian (RANK) model brings the model closer to a heterogeneous agent New Keynesian (HANK) model (Kaplan et al. (2018)).

The liquidity demand parameters $\{\nu, \phi\}$ map to parameters estimated in other empirical work. $\nu \in \mathbb{R}$ is the debt-invariant spread on real interest rate, and $\phi \in \mathbb{R}_{++}$ is the semi-elasticity of the real interest rate spread with respect to bonds. Increasing $\nu$ raises the marginal utility of liquidity at all levels of debt, while increasing $\phi$ makes liquidity demand more elastic. $\nu$ dictates the level of liquidity demand and $\phi$ controls the demand elasticity.

Other recent papers use a variation of this functional form. These papers (e.g. Krishnamurthy and Vissing-Jorgensen (2012), Angeletos et al. (2023), Mehrotra and Sergeyev (2021), Kekre and Lenel (2021), Mian et al. (2022)) typically parameterize the marginal value of liquidity with a linear-log specification (e.g. $w_b(b, s^t) = \nu_t - \phi \log(b)$), whereas I use a linear-inverse hyperbolic sine specification. My specification allows for negative debt ratios $b < 0$, which the linear-log specification mechanically rules out. The inverse hyperbolic sine function permits negative debt while still fitting the shape of the Treasury demand function. Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood and Vayanos (2010) find that the linear-log specification describes the demand for public debt's liquidity.

### 2.3.2 Preferences and Optimization

The household consumes goods $C_t$, supplies labor $N_t$, and buys one-period real bonds $B_{t+1}(s^{t+1})$. Let $b_t = \frac{B_t(s^t)}{Y_t}$ be the time-varying debt ratio. Households preferences,

$$\max_{\{C_t, N_t, B_{t+1}\}_t} \mathbb{E}_0 \sum_t \beta^t \sum_{s^t} \Omega_t [u(C_t) - v(N_t) + w(b_t)], \tag{2}$$

are time-separable in consumption utility $u(C_t) = \frac{C_t^{1-\sigma}-1}{1-\sigma}$, labor disutility $v(N_t) = \Xi \frac{N_t^{1+\eta}}{1+\eta}$, and liquidity demand $w(b_t)$. Where $\beta \in (0,1)$ is the discount rate, $\sigma \geq 0$ is the inverse of the intertemporal elasticity of substitution (IES), $\eta > 1$ is the inverse of the Frisch elasticity, $\Xi > 0$ is the value of nonmarket time, $\nu \in \mathbb{R}$ is the debt-invariant spread on real interest rate, and $\phi \geq 0$ is the semi-elasticity of the real interest rate spread with respect to bonds.

The household takes labor taxation $\tau_t$, interest rate on bonds $R_t$, government transfers $T_t$, and output $Y_t$ as given. While the household owns the firm, there are no profits. For a given history $s^t$ the household chooses consumption $C_t$, labor supply $N_t$, and their real bond holdings $B_{t+1}$ to maximize their utility function (equation 2) given their time $t$ household budget constraint,

$$C_t + \frac{B_{t+1}}{R_t} = (1 - \tau_t) N_t + B_t + T_t. \tag{3}$$

Optimization by the household leads to two first order conditions. The first optimality condition is the labor-leisure decision,

$$(1 - \tau_t) = \frac{v_{N,t}}{u_{C,t}}. \tag{4}$$

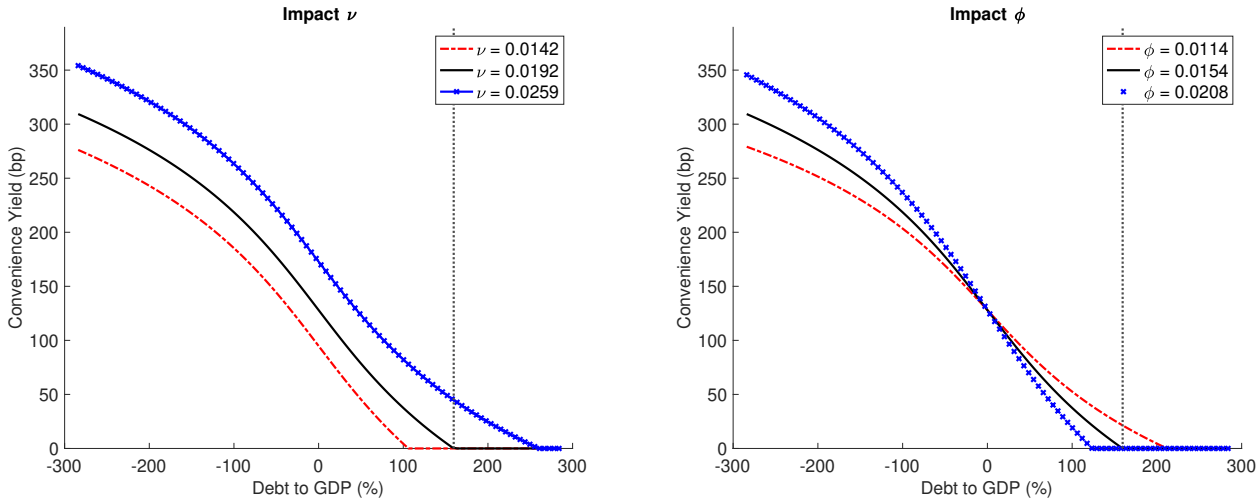



Figure 2: **Convenience yield on public debt.** The x-axis denotes the the debt ratio and the y-axis denotes the convenience yield on public debt in basis points. The left panel plots the convenience yield for different values of the liquidity spread parameter $\nu$. The right panel plots the convenience yield for different values of the liquidity demand elasticity parameter $\phi$.

The labor-leisure decision (equation 4) represents the tradeoff between consuming an additional unit this period $u_{C,t}$ and working an extra unit $v_{N,t}$. Holding consumption $C_t$ fixed, higher taxes $\tau_t$ reduce labor supply $N_t$. Holding labor supply $N_t$ fixed, higher taxes $\tau_t$ reduce consumption $C_t$. The second optimality condition is the liquidity-adjusted Euler equation,

$$\frac{1}{R_t} = \underbrace{\beta \sum_{s^{t+1}} \Omega_{t+1|t} \left[\frac{u_{C,t+1}}{u_{C,t}}\right.}_{\text{Consumption-Savings}} + \underbrace{\left.\frac{w_{b,t+1}}{u_{C,t} Y_{t+1}}\right]}_{\text{Liquidity-Demand}}. \tag{5}$$

The first term on the right hand side of the liquidity-adjusted Euler equation (5) captures household's demand for savings, while the second captures the demand for liquidity. Standard Euler equations solely capture the consumption-savings decision of the household; the tradeoff between consuming an additional unit this year $u_{C,t}$ or saving this additional unit and consuming more next year $u_{C,t+1}$. Beyond their role as a savings device, in my model bonds $B_{t+1}$ provide liquidity service. Liquidity demand produces a downward sloping demand for bonds $B_{t+1}$ for a given interest rate $R_t$. The marginal utility of liquidity, plotted in figure 2, illustrates this downward sloping demand curve.

Household demand for liquidity produces a convenience yield on public debt. Let $R_t^{CS}$ be the *consumption-smoothing* interest rate, i.e. the prevailing interest rate when liquidity is satiated. Where,

$$R_t^{CS} = \beta^{-1} \frac{u_{C,t}}{\sum_{s_{t+1}} \Omega(s_{t+1}|s^t)[u_{C,t+1}]}. \tag{6}$$

For debt ratios $b_{t+1}$ *above* the liquidity-satiation level $b^{liq.sat.}$ (dotted vertical line), households

demand bonds solely for consumption smoothing. If the debt ratio $b_{t+1}$ is *below* the liquidity-satiation level $b^{liq.sat.}$, households demand bonds for both consumption smoothing and liquidity provision. Excess demand for bonds $B_{t+1}$ produces a spread between the interest rate of bonds $R_t$ and the consumption-smoothing interest rate $R_t^{CS}$. The convenience yield on public debt is the difference between the interest rate $R_t$ and the consumption-smoothing interest rate $R_t^{CS}$. Since there is no growth in this model, the interest rate spread $R_t - R_t^{CS}$ is the model equivalent of the $r-g$ spread discussed by Blanchard (2019).

## 2.4 Market Clearing

There is market clearing in the goods market and the bond market. Goods market clearing requires that household consumption $C_t$ and government expenditure $G_t$ must equal output $Y_t = F(N_t) = N_t$ each period. That is,

$$C_t + G_t = N_t. \tag{7}$$

Goods market clearing (equation 7) describes the demand for labor, while the labor-leisure decision (equation 4) describes the supply of labor. Together they pin down the equilibrium output $N_t$ for a given tax rate $\tau_t$.

Bond market clearings requires that household bond holdings $B_t$ must equal the government's supply of public debt. The liquidity-adjusted Euler equation (5) together with the household budget equation (3) pins down the real interest rate $R_t$ for a given debt level $B_{t+1}$. Households do not internalize market clearing restrictions.

## 2.5 Government

Policymakers affect the decisions of households and firms through government policy $p_t = \{\tau_t, T_t, B_{t+1}\}$. Where $\tau_t$ is labor taxation, $T_t$ is lump-sum transfers to the household, and $B_{t+1}$ is real debt issued. The government linearly taxes labor and provides lump-sum transfers. Lump-sum taxes are ruled out due to unmodeled wealth heterogeneity. Heathcote et al. (2017) argue that this taxation scheme approximates the U.S. tax system.

The government faces surplus risk in the form of exogenous shocks to government spending $G_t$. When elevated I refer to these shocks as "wars" or "crises." The government faces an intertemporal budget constraint,

$$\frac{B_{t+1}}{R_t} = B_t + \overbrace{G_t - \tau_t N_t + T_t}^{\text{Primary Deficit at } t}. \tag{8}$$

The government uses four tools to pay for outstanding debt $B_t$ and government expenditure $G_t$: labor taxation $\tau_t$, debt rollover $B_{t+1}$, inflation $\Pi_t = \frac{P_t}{P_{t-1}}$, and liquidity taxation $\omega_t$. Let $\omega_{t+1} = \frac{w_{b,t+1}}{u_{C,t}}$

be the tax on liquidity. Labor taxation, debt rollovers, and inflation are standard in optimal debt models. While inflation $\Pi_t$ is not explicitly defined in this economy, state-contingent real debt is equivalent to risk-free *nominal debt* $B_t^{nom}(s^{t-1})$ subject to costless state-dependent inflation $P_t$ (Bohn (1990)). Explicitly, $B_t(s^t) = B_{t-1}^{nom}(s^{t-1})/P_t(s^t)$. In later sections I rule out state-contingent debt and require that the government only issue risk-free *real* debt $B_{t-1} = B_t(s^{t-1})$. Restricting the government to only issuing risk-free real debt rules out the possibility of using inflation $\Pi_t$ to pay for outstanding debt $B_t$.

Taxing liquidity is implemented by undersupplying public debt. To illustrate, I decomposes the value of debt issuance $\frac{B_{t+1}}{R_t}$ into it's savings and liquidity value:

$$\frac{B_{t+1}}{R_t} = \underbrace{\frac{B_{t+1}}{R_t^{CS}}}_{\text{Savings value}} + \underbrace{\mathbb{E}_t[\omega_{t+1} b_{t+1}]}_{\text{Liquidity value}}. \tag{9}$$

Savings value of debt is the present discounted value of future primary surpluses. Liquidity value of debt is the present discounted value of future liquidity services[3]. The liquidity tax is zero if liquidity demand is satiated $b_{t+1} \geq b^{Liq.Sat.}$ and positive if liquidity is not satiated $b_{t+1} < b^{Liq.Sat.}$. If the debt ratio is below the satiating level, $b_{t+1} < b^{Liq.Sat.}$, the government effectively taxes liquidity by supressing the interest rate, $R_t < R_t^{CS}$. Just as inflation is a tax on money's liquidity services (Phelps (1973), Kimbrough (1986) and, Leeper and Zhou (2021)), interest rate suppression $R_t < R_t^{CS}$ represents a tax on government bond's liquidity services. Others (e.g. Blanchard (2019), Mankiw (2022), and Barro (2022)) refer to this suppression as "debt seignorage." I describe this interest rate suppression as a liquidity tax to avoid confusion with the monetary definition of seignorage.

First-best policy calls for eliminating labor taxes $\tau_t = 0, \forall t$ and satiating liquidity demand $b_t \geq b^{Liq.Sat.}, \forall t$. Excising labor and liquidity taxation removes the policy-induced wedges in the labor-leisure decision (equation 4) and the liquidity-adjusted Euler equation (5) respectively. Insulating households from the distortionary effects of government expenditure shocks. Policymakers with access to lump-sum taxes and transfers can implement first-best policy. Ruling out lump-sum taxation forces the government to resort to distortionary labor and liquidity taxation. Government policy is also restricted by labor and liquidity Laffer curves, natural debt and asset limits, and the state-contingency of debt. I discuss these restrictions in detail in Sections 2.5.1, 2.5.2, and 2.5.3.

### 2.5.1 Laffer Curves

Laffer curves for both labor and liquidity taxation limit policymakers ability to raise tax revenues. The labor Laffer curve constrains taxation policy and the liquidity Laffer curve constrains debt policy. The former produces a maximum labor tax rate and the latter produces a maximum liquidity tax.

The labor Laffer curve emerges from the direct and indirect effect of increased labor taxes $\tau_t$ on labor tax revenues $\tau_t N(\tau_t)$. Directly, labor taxation $\tau_t$ raises the tax revenue per unit of labor

[3] Brunnermeier et al. (2022) calls this term a bubble on government debt.

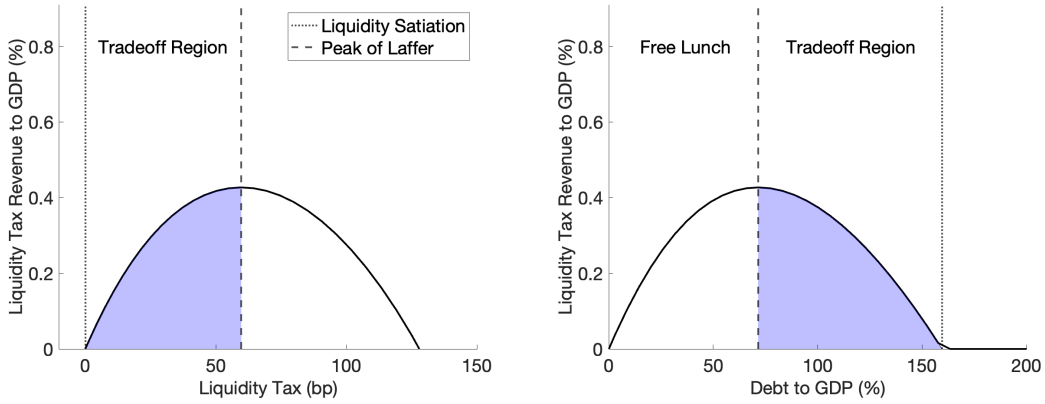



Figure 3: **Liquidity and debt Laffer curves.** This figure plots the tax revenue from the liquidity tax. The left panel plots the liquidity Laffer curve: liquidity tax against the liquidity tax revenue. The right panel plots the debt Laffer curve: debt ratio against the liquidity tax revenue.

supply $N_t$. Indirectly, labor taxes $\tau_t$ reduce labor supply $N(\tau_t)$ by disincentivizing households to work. Together these forces generate an inverted-U shaped Laffer curve for labor tax revenues with a single peak. The direct effect dominates to the left of the peak while the indirect effect dominates to the right. The peak of the Laffer curve corresponds to a state-dependent upper bound on labor taxation $\tau_t \leq \bar{\tau}_t$, beyond which tax revenues decline. Elevated government expenditure $G_t$ increases labor demand and consequently raises the peak of the Laffer curve: $G_t > G_t' \Rightarrow \bar{\tau}_t > \bar{\tau}_t'$. Policymakers should never set labor taxes to the right of the labor Laffer curve peak as there is a lower labor tax that produces the same revenue. The maximal labor tax rate resembles those estimated by Trabandt and Uhlig (2011).

The same intuition from the labor Laffer curve applies to the liquidity Laffer curve. The left panel of figure 3 plots the liquidity Laffer curve as the liquidity tax revenue $\omega_t b(\omega_t)$ for a given liquidity tax $\omega_t$. In the public finance literature, Laffer curves are typically drawn like the liquidity Laffer curve with the tax rate on the x-axis. The direct effect of raising liquidity taxes initially raises revenue. However for high enough liquidity taxes the indirect effect dominates and liquidity tax revenue declines. This tradeoff between the direct and indirect effects generates the inverted U-shape common to Laffer Curves. The peak of the liquidity Laffer curve is the liquidity tax that maximizes liquidity tax revenue, $\omega^{Laffer} = \arg\max_{\omega} \omega b(\omega)$.

The intuition from the liquidity Laffer curve is flipped for the debt Laffer curve. The right panel of figure 3 plots the debt Laffer curve as the liquidity tax revenue $\omega(b_t)b_t$ for a given debt level $b_t$.. Directly, reducing debt ratio $b_t$ reduces liquidity tax revenues. Indirectly, reducing the debt ratio raises the liquidity tax $\omega(b_t)$ by making liquidity more scarce. Debt ratio reduction increases the marginal value of liquidity, $w_{b,t}$, suppresses interest rates $R_t$ and raises the liquidity tax $\omega(b_t)$. The peak of the debt Laffer curve is the debt ratio that maximizes liquidity tax revenue, $b^{Laffer} = \arg\max_{b} \omega(b)b$. The peak of the debt Laffer curve $b^{Laffer}$ maps directly to the peak of the liquidity Laffer curve $\omega^{Laffer} = \omega(b^{Laffer})$. For the particular function form of liquidity demand outlined in equation , the peak of this debt Laffer curve is $b^{Laffer}$ is *below* the debt satiating level $b^{liq.sat.}$.

The liquidity and debt Laffer curves help visualize optimal taxation and debt policy. First-best policy is to set labor and liquidity taxes to zero. Graphically, the first-best policy corresponds to the *left* foot of the liquidity Laffer curves and the *right* foot of the debt Laffer curve. Absent shocks, optimal policy should never set the liquidity tax to the *right* of the liquidity Laffer curve peak or to the *left* of the debt Laffer curve peak. For any liquidity tax rate to the right of the peak there exists a tax rate to the left of the peak that raises the same revenue while imposing a lower tax rate on households. Absent shocks, optimal liquidity taxes will be set in the tradeoff region between the minimum and maximum tax. On the liquidity Laffer curve this tradeoff region is to the *left* of the peak, while on the debt Laffer curve this region is to the *right* of the peak. Mian et al. (2022) refer to the area left of the debt Laffer curve peak as the "free-lunch" region. This "free-lunch" region maps to the right region of the liquidity Laffer curve. In this region the government can increase debt and raise liquidity tax revenues. Absent shocks, optimal debt policy should set the debt ratio somewhere in the tradeoff region between the peak of the debt Laffer curve and the liquidity satiating debt ratio. With shocks, the optimal debt level can be in this "free-lunch" region.

The liquidity satiation point is the bond equivalent of the Friedman (1971) rule for money. At this point, policymakers flood the market with liquid bonds, setting liquidity taxes to zero. While the peak of the debt Laffer curve is the bond equivalent of the Phelps (1973) rule for money. At this point, policymakers extract maximal liquidity taxes from bond holders by sapping the market of liquidity.

### 2.5.2 Natural Debt and Asset Limits

Liquidity demand does not raise the government's debt limit. Government's debt is limited by the "natural debt limit:" the maximum level of indebtedness at which the government debt can almost surely be repaid (Aiyagari (1994)). In order to find this debt limit, I consider the worst case scenario in which the government is stuck in a perpetual war while heavily indebted. In this scenario government expenditure $G_t$ remains at its highest level $\bar{G}$ for all periods $t$ and states $s^t$, public debt has reached its peak $\bar{B}$ and labor taxes must be set at the peak of their Laffer curve $\bar{\tau} = \bar{\tau}(\bar{G})$ to pay for both the war and the interest payments on the debt. Continually high taxes generate continually low output $\underline{\mathrm{N}}$. In this scenario, the real interest rate, $\bar{R}(\bar{B}) = \beta^{-1}\frac{\underline{\mathrm{N}}}{\underline{\mathrm{N}}+w_b(\bar{B}/\underline{\mathrm{N}})}$, depends on the convenience yield of public debt $w_b(\bar{B}/\underline{\mathrm{N}})$ at the natural debt limit $\bar{B}$. However, for all reasonable calibrations the natural debt limit lies above the debt satiating level. Therefore at the natural debt limit liquidity will be satiated. Therefore the convenience yield will be zero and the natural debt limit is unaffected by liquidity demand [4].

While the convenience yield on public debt has no impact on the natural debt limit, it raises the government's asset limit. The natural asset limit is defined as the maximum asset level (i.e. neg-

[4]There are two cases: either the natural debt limit is large enough, $\bar{B} \geq b^{liq.sat}\cdot\underline{\mathrm{N}}$, that the convenience yield on public debt disappears, that is $\bar{R}(\bar{B}) = \beta^{-1}$, or the natural debt limit is low enough, $\bar{B} < b^{liq.sat}\cdot\underline{\mathrm{N}}$, to reduce the interest rate, that is $\bar{R}(\bar{B}) < \beta^{-1}$. When the natural debt limit is large enough $\bar{B} \geq b^{liq.sat}\cdot\underline{\mathrm{N}}$ to eliminate the convenience yield, the natural debt limit is identical to Bhandari et al. (2017a): $\bar{B} = \frac{\bar{\tau}\underline{\mathrm{N}}-\bar{G}}{1-\beta}$. For this natural debt limit $\bar{B}$ to generate convenience yield, requires enormous government expenditure shocks: $\bar{G} > \bar{\tau}\underline{\mathrm{N}} - (1-\beta)\exp\{\nu/\phi\}$. Far above any reasonable parameterization.

ative debt level) at which all future government expenditure can be covered without labor taxes. In this scenario government expenditure $G_t$ remains at its highest level $\bar{G}$ for all periods $t$ and states $s^t$, public assets are at their peak $\underline{\mathrm{B}}$ and labor taxes are uniformly zero $\tau = 0$. At this limit, interest on assets covers all government expenditure. In this scenario, the real interest rate, $\bar{R}(\underline{\mathrm{B}}) = \beta^{-1}\frac{\bar{N}}{\bar{N}+w_b(\underline{\mathrm{B}}/\bar{N})}$, is suppressed by the convenience yield of public debt $w_b(\bar{B}/\bar{N})$ at the natural asset limit $\underline{\mathrm{B}}$. Since the government is earning less interest on its assets, it must acquire more assets to pay for government expenditure $\bar{G}$ each year. This effect raises the natural asset limit.

### 2.5.3 Contingent and Noncontingent Debt

The value of state-contingent debt $B_{t+1}(s^{t+1})$ issued at year $t$ after observing history $s^t$ is contingent on history $s^{t+1} = (s^t, s_{t+1})$. With access to state-contingent debt, the government can vary payoffs at year $t+1$ based on the ex-post government expenditure level $G_{t+1}$. Therefore markets are complete in the sense that public debt can insure against future shocks. The value of noncontingent debt $B_t(s^t)$ issued at year $t$ after observing history $s^t$ is only contingent on the observable history of shocks $s^t$. Payoffs are not contingent on the ex-post government expenditure level $G_{t+1}$. Therefore markets are incomplete in the sense that public debt cannot insure against future shocks.

While issuing explicitly state-contingent debt is antithetical to modern practice in the United States there exist a multitude of microfoundations and historical precedent. Ex-post devaluation of nominally risk-free debt through inflation replicates state-contingent debt, as long as the Phillips curve is vertical (Bohn (1990), Chari et al. (1991),Siu (2004), and Bhandari et al. (2017b)). Partially defaulting on real debt also replicates state-contingent debt (Grossman and Van Huyck (1985), Adam and Grill (2017), and Arellano et al. (2023)). Finally, state-contingent debt can be replicated through issuing a suite of risk-free real bonds of differing maturities (Angeletos (2002), Buera and Nicolini (2004), and de Lannoy et al. (2022)). Debt devaluations lengthen the maturity of debt, State-contingency resembles the post-Civil War and Great Depression debt management of the United States.

The state contingency of public debt radically alters optimal debt policy. Therefore sections 3 and 4 consider optimal policy in economies with state-contingent and noncontingent debt separately.

## 2.6 Equilibrium

A *feasible government policy* is a government policy $p_t = \{\tau_t, T_t, B_t\}$ which respects (i) the Labor laffer curve (ii) the natural debt and asset limits and (iii) the lower bound on lump-sum transfers $T_t \geq 0$. For a given feasible government policy, a *competitive equilibrium* is a sequence $\{C_t, N_t, R_t\}$ that satisfies (i) optimality for households (ii) optimality for firms (iii) market clearing and (iv) the government's intertemporal budget. The *Ramsey problem* is to maximize household welfare (equation 2) over all competitive equilibrium. Formal definitions for the italicized terms (e.g. *feasible government policy*) included in Appendix A.

The Ramsey problem features a unique optimal debt target for each government expenditure level. The policy problem is inherently non-convex. Despite this non-convexity, the problem satisfies the

Skiba (1978) conditions laid out by Angeletos et al. (2023) (Sec 4.C). Absent shocks, debt and taxes converge monotonically to a unique level for each government expenditure level.

## 2.7 Computation

In Sections 3 and 4, I characterize optimal Ramsey policy for a government with state-contingent and noncontingent debt instruments. In both cases i solve for the globally optimal solution using standard methods. Ljungqvist and Sargent (2018) solve for optimal Ramsey policy in the complete markets model of Lucas and Stokey (1983) (Sections 20.2) and the incomplete markets model Aiyagari et al. (2002) (Sections 20.3) with the same methodology. Alternatively, the recursive contracts method of Marcet and Marimon (2019) could be used to find the solution. The central difference between my model and the textbook model in Ljungqvist and Sargent (2018), is that the value of government debt includes the liquidity services it provides. Details on the computation of the complete and incomplete markets Ramsey policy included in Appendices B and C.

## 2.8 Calibration

My calibration is summarized in Table 1. The model period is one year. I set the discount factor $\beta$ to match the average return on AAA rated corporate bonds since 1925. I set the intertemporal elasticity of substitution to the standard value of 1 and the Frisch elasticity to .5 to match the estimates of **?**.

| Parameter | Description | Value | Target |
|---|---|---|---|
| $\sigma^{-1}$ | Intertemporal elasticity of substitution | 1 | Standard |
| $\eta^{-1}$ | Frisch Elasticity | 1/2 | Chetty et al. (2011) |
| $\Xi$ | Labor disutility | 1.5 | Prescott (2004) |
| $\beta$ | Discount factor | .95 | Return on AAA corporate bonds |
| $\nu$ | Interest rate spread on liquid assets | .0192 | Convenience yield on public debt |
| $\phi$ | Semi-elasticity of interest rate spread with public debt | .0154 | Convenience yield on public debt |

Table 1: **Baseline Calibration.**

By log-linearizing the liquidity-adjusted Euler equation (5) around steady state, I can write the convenience yield $r_t^{LS} - r_t$ in terms of the structural liquidity demand parameters $\{\nu, \phi\}$ and the debt ratio $b_t$: $\frac{Y}{C}(r_t^{LS} - r_t) = \nu - \phi \sinh^{-1}(b_t)$[5] . I use the spread between AAA corporate bonds $r_t^{AAA}$ and long-maturity Treasury bonds $r_t^{Tres.}$ as a proxy for the convenience yield $r_t^{LS} - r_t$. AAA corporate bonds are similarly safe to Treasury bonds but do not offer the same liquidity services.

I calibrate the liquidity demand parameters $\{\nu, \phi\}$ to match the convenience yield on public debt. Extending Krishnamurthy and Vissing-Jorgensen (2012)'s data, I calculate the interest rate spread $r_t^{AAA} - r_t^{Tres.}$ annually from 1919 to 2022. Similarly, I calculate the debt held by the public as a percent of GDP $b_t$ over the same period. Since 1945, consumption-to-output $\frac{C}{Y}$ has been relatively

[5]Let $\frac{1}{R_t^{AAA}} = \mathbb{E}_t \beta \frac{u_{C,t+1}}{u_C(C_t)}$, then by the liquidity-adjusted Euler equation (5) $\frac{1}{R_t} = \frac{1}{R_t^{AAA}} + \mathbb{E}_t[\frac{w_b(b_t)}{Y_t u_C(C_t)}]$. Let consumption and output be constant $C_t = C, Y_t = Y$. Log-linearization of each side reveals $r_t^{AAA} - r_t^{Tres.} = \frac{C}{Y} w_b(b_t)$.

stable at 66%. I regress the scaled interest rate spread $\frac{Y}{C}(r_t^{AAA} - r_t^{Tres.})$ on a constant and hyperbolic sine of the debt ratio $\ln\left(b_t + \sqrt{b_t^2+1}\right)$ to recover the estimated parameters $\{\hat{\nu}, \hat{\phi}\}$. These parameter values imply that the liquidity satiating level of the debt ratio is 160% and the peak of the debt Laffer curve is 72%. Repeating this estimation procedure with Krishnamurthy and Vissing-Jorgensen (2012)'s linear-log specification yields similar parameters, debt satiation levels, and debt Laffer peaks.

### 2.8.1 Government Expenditure Shocks

| Parameter | Description | Value |
|---|---|---|
| $G^{low}$ | Low government expenditure level | .2 |
| $G^{high}$ | High government expenditure level | .45 |
| $\rho^{low}$ | Low government expenditure state persistence | .95 |
| $\rho^{high}$ | High government expenditure state persistence | .75 |
| $\sigma^G$ | Yearly Variation | .03 |

Table 2: **Government Expenditure Shocks.** All values calibrated to match the the level and change in annual government expenditure (GCEA in FRED) to output (GDPA in FRED) ratio from 1929 to 2022. Calibrated using a two-state Markov-switching dynamic regression model.

Table 2 describes the estimated government expenditure process. To generate the stochastic government expenditure process $G_t$, I fit a two-state Markov-switching dynamic regression model, $G_t = G_t^{MC} + \varepsilon_t$, to the annual government expenditure to output ratio from 1929 to 2022. Where $G_t^{MC}$ is a two-state Markov chain and $\varepsilon_t \sim N(0, \sigma^G)$ is yearly i.i.d. noise. This measure of government expenditure includes total national defense, income security, education and general government spending. It does not include transfers.

I define the government expenditure to output ratio as the ratio of nominal government consumption and investment (GCEA in FRED) to the nominal gross domestic product (GDPA in FRED). Fitting the model reveals that the low government expenditure state is $\hat{G}^{low} = .2$, high government expenditure state is $\hat{G}^{high} = .45$, low state persistence is $\hat{\rho}^{low} = .99$, and high state persistence is $\hat{\rho}^{high} = .75$. In order to better match the probability of a crisis in the United States since 1860, I set the persistence of low states to be $\rho^{low} = .95$. For the other parameters $\{G^{high}, G^{low}, \rho^{low}, \& \ \sigma^G\}$ I use the estimated values. In this calibration, crises occur every 20 years and last for 4 years; the probability of being in crisis in any given year is 17%.

This shock process in conjunction with the parameter values in Table 1 imply that the natural asset limit is -3,418% of GDP and the natural debt limit is 269% of GDP.

# 3 Optimal Policy with Contingent Debt

This section characterizes the optimal Ramsey policy for an economy with complete markets. Compared to optimal policy without liquidity demand, labor taxes are more volatile, the public debt

is less volatile, and the inflation tax is smaller. Optimal policy is characterized by a central tradeoff between reducing labor and liquidity tax volatility. The relative desirability of each depends on the degree of liquidity demand and the labor supply response to labor taxes. The former is dictated by the liquidity demand parameters and latter by the Frisch elasticity.

## 3.1 Ramsey Problem

Let $\mathscr{B}(B,G,N) = u_c B + w_b \frac{B}{N}, \mathscr{T}(G,N) = u_c \tau(N) N, \mathscr{Q}(b) = w_b b, \mathscr{G}(G,N) = u_c G$, and $\mathscr{R} = \frac{1}{\beta}$ be the marginal utility adjusted debt, labor tax revenues, liquidity tax revenue, government expenditure, and interest rate. For brevity I refer to the first three variables as the values of debt, tax revenue, and government expenditure. For notational convenience I omit their dependence on $(B,G,N)$. The Ramsey planners optimal value function for $t \geq 1$ satisfies the Bellman equation:

$$\begin{aligned} V(\mathscr{B},G) = \max_{(B,N,\mathscr{B}_s)\in\Phi(\mathscr{B},G)} & u(N-G) - v(N) + w(\frac{B}{N}) + \beta \sum_s \Omega_s(G) V(\mathscr{B}_s, G_s) \\ \text{where } \Phi(\mathscr{B},G) = & \{(B,N,\mathscr{B}_s) \in CE(\mathscr{B},G) : \mathscr{B} + \mathscr{G} \leq \mathscr{T} + \mathscr{Q} + \sum_s \Omega_s(G) \frac{\mathscr{B}_s}{\mathscr{R}}\}. \end{aligned} \tag{10}$$

Where $\Omega_s(G)$ is the probability of state $G_s$ conditional on state $G$ and $CE(\mathscr{B},G)$ is the competitive equilibrium defined in section 2.6. Without liquidity demand, the Ramsey problem (10) is identical to Lucas and Stokey (1983). The construction of this Ramsey problem along with the time 0 Ramsey problem can be found in Appendix B.

## 3.2 Theory of Labor and Liquidity Tax Smoothing

In standard models with contingent debt, optimal debt policies critically depend on the labor tax-smoothing motive of policymakers. Labor taxes reduce welfare by distorting household's labor-leisure decision (equation 4). Ideally, the policymaker would set labor taxes to zero in all periods to eliminate these distortions. Given that lump-sum taxes are unavailable, labor taxation becomes necessary to cover expenditure shocks. Second-best policy smoothes these distortion across periods (Barro (1979)).

In my model, optimal debt policies also critically depend on the *liquidity* tax-smoothing motive of policymakers. Liquidity taxes distort the household's savings decision (equation 5). First-best policy sets liquidity taxes to zero. Similar to the Friedman (1971) policy prescription for money, this policy outcome is achieved by flooding the market with public debt. Optimal debt policy and optimal liquidity tax policy are two-sides of the same coin. Second-best policy smoothes the savings decision distortions across periods by keeping the debt level constant.

With state-contingent debt, the policymaker can perfectly smooth labor taxes. Smoothing labor taxes across periods of high and low government expenditure requires ex-post debt revaluations. When expenditure is high the value of debt holdings declines to keep total government expenditure

– government expenditure and interest payments – constant across states. Policymakers keep labor taxes smooth by allowing debt to fluctuate.

Absent liquidity demand these debt revaluations have no direct welfare impact on households. If the household demands liquidity, debt reductions deprive the economy of liquidity (Angeletos et al. (2023) and Sims (2024)). Debt fluctuation raise liquidity tax volatility. Second-best labor and liquidity tax policy are at odds. Since simultaneously smoothing labor taxes and debt is impossible the policymaker faces a tradeoff between tax instruments. Without liquidity demand the policymaker perfectly smooths labor taxes. With strong enough liquidity demand the policymaker perfectly smooths liquidity taxes.

## 3.3 Characterizing Optimal Policy

### 3.3.1 Optimal Policy Response

Figure 4 plots the optimal policy response from steady-state to a surprise expenditure shock. The figure illustrates optimal policy responses for three models. Specifically, "full liquidity" in which the liquidity demand parameters $(\nu, \phi)$ are set to the baseline calibration in table 1; "partial liquidity" in which the liquidity demand parameters are both 1/5th the baseline calibration; and "no liquidity demand" which sets both liquidity demand parameters to zero. The government expenditure shock starts in period 20 and lasts for 10 years. Prior to the shock there is a long period of low expenditure. Each year the policymaker is uncertain if the crisis will persistent another year. Labor taxes, liquidity taxes, and interest rates rise while debt to output falls.

Across all three models, I initialize the debt so that the steady-state debt ratio is above 125% and the debt ratio remains positive throughout the exercise. The initial debt level influences the steady-state debt ratio. With state-contingent bonds and no liquidity demand, policymaker smooths all future labor taxes at a level commensurate with the initial debt level. In this case, the average debt ratio is an increasing function of the initial debt. With liquidity demand, there is a unique average debt ratio independent of the initial debt. Further discussion of debt determinacy can be found in Appendix B.6.

The magnitude of the labor tax increase during the crisis is proportional to the degree of liquidity demand. Without liquidity demand, labor taxes do not change, with some liquidity demand labor taxes increases by 2%, and with full liquidity demand labor taxes increase by 7%. Persistent crises lead to larger increases in labor taxes than transitive episodes. For instance, a 1% labor increase for a one year crisis and a 5% labor increase for a twenty year crisis.

In the absence of liquidity demand, the policymaker devalues the debt by 60% at the start of the war, reducing the debt ratio by 105%. This devaluation is sufficiently large to keep the policymaker from raising labor taxes. With full liquidity demand, the policymaker still devalue debt at the start of the war, but this devaluation only reduces the debt ratio by 77%. This devaluation is insufficiently large to cover the surprise expenditure, forcing the policymaker to make up the budget shortfall by raising labor taxes.

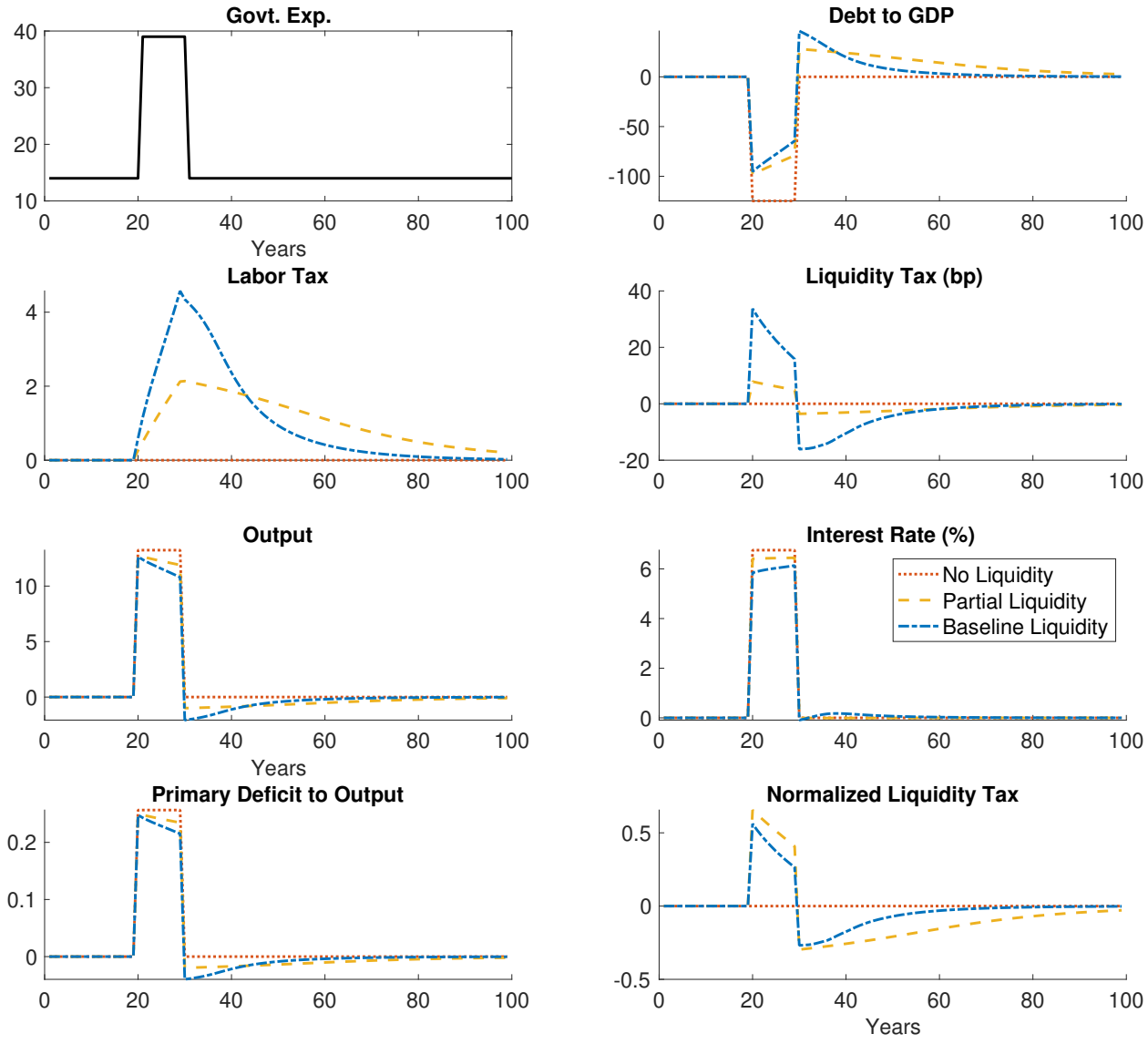



Figure 4: **Optimal policy response with complete markets.** This figure plots the optimal policy response to an unforeseen government expenditure shock in the complete markets model. In the baseline liquidity, partial liquidity, and no liquidity model the demand parameters equal $\{\nu, \phi\}$, $\{.2\nu, .2\phi\}$, and $\{0, 0\}$. The government expenditure shock starts in period 20 and lasts for 10 years. Prior to the shock there is a long period of low expenditure. The top left panel plots a single government expenditure shock. The remaining panels plot the differences from steady-state for each variable. Output is plotted as the percent difference while the remaining variables are plotted as level differences.

In order to compare the volatility of liquidity taxes between models with varying degrees of liquidity demand, I compare *relative liquidity taxes*. I define the relative liquidity tax as the ratio of the prevailing liquidity tax to the liquidity tax at the peak of the debt Laffer curve. The parameters $\nu$, the liquidity spread, and $\phi$, the semi-elasiticity of the spread, dictate the degree of liquidity demand. Dividing both parameters by the same factor decrease the degree of liquidity demand but leaves the liquidity satiating debt ratio$b^{Liq.Sat.}$ and peak of the debt Laffer curve $b^{Laffer}$ unchanged

This allows for clear comparisons of optimal debt levels across models. However these parameters dictating liquidity demand also dictate the magnitude of the liquidity tax $\omega_t$. Therefore models with greater liquidity demand will mechanically produce a larger liquidity tax for a given debt ratio. The relative liquidity tax helps accounts for this mechanical effect.

As the degree of liquidity demand increases the volatility of liquidity taxes increases while the volatility of the normalized liquidity tax decreases. Liquidity demand mechanically increases the magnitude and volatility of liquidity taxes. Moving from an economy with some liquidity demand to the baseline calibration, a tenfold increase in the degree of liquidity demand, increases the magnitude of liquidity taxes by 1.2 basis points and the volatility by 1.8 basis points. Higher degree of liquidity demand leads to smoother normalized liquidity taxes. With some liquidity demand, normalized liquidity taxes jump .6 on impact while for full liquidity they jump .5. With complete markets, optimal policy calls for taxing liquidity during crises.

The policymaker aims to simultaneously smooth labor and liquidity taxes. Absent implausibly large output and interest rate responses, perfectly smoothing both taxes is infeasible[6]. Therefore the policymaker faces a tradeoff: smooth labor taxes by ex-post revaluing the debt or smooth liquidity taxes by limiting debt revaluations. Higher liquidity demand leads the policymaker to favor liquidity tax smoothing. More responsive labor supply leads the policymaker to favor labor tax smoothing. This tradeoff is discussed in more detail in Appendix B.5.

## 3.4 Taxation Decomposition

Each year, the policymaker must cover exogenous government expenditure. There are four tools at the policymaker's disposal: (1) labor taxes (2) liquidity taxes (3) inflation taxes and (4) debt rollover. The policymaker can tax labor income, tax government debt's liquidity services, reduce the value of last year's debt through inflation, or issue new debt. By rearranging the government budget equation (8), I decompose the government expenditure across these four tools:

$$G_t = \overbrace{\tau_t N_t - T_t}^{\text{Labor Tax Rev.}} + \underbrace{\mathbb{E}_t[\omega_{t+1} b_{t+1}]}_{\text{Liquidity Tax Rev.}} + \overbrace{(\mathbb{E}_{t-1}[B_t] - B_t)}^{\text{Inflation Tax Rev.}} + \underbrace{(\frac{B_{t+1}}{R_t^{CS}} - \mathbb{E}_{t-1}[B_t])}_{\text{Debt Rollover}}. \tag{11}$$

I define the net labor tax income $\tau_t N_t - T_t$ as the labor tax revenue, the average expected liquidity tax income $\mathbb{E}_t[\omega_{t+1} b_{t+1}]$ as the liquidity tax revenue, the difference between expected and actual real debt $\mathbb{E}_{t-1}[B_t] - B_t$ as the inflation tax revenue, and the difference between the savings's value of newly issued and expected real debt $\frac{B_t}{R_t^{CS}} - \mathbb{E}_{t-1}[B_t]$ as the value of debt rollover. I use the consumption smoothing interest rate $R_t^{CS}$ rather than the prevailing interest rate $R_t$ to differentiate between liquidity taxation and debt rollover.

This decomposition, visualized in Figure 5, allows comparison of each tools importance across states of the world. The left panel plots the government expenditure shock, and the middle and right

[6]Simultaneously insuring tax payers and government bond holders is impossible (Jiang et al. (2020)).

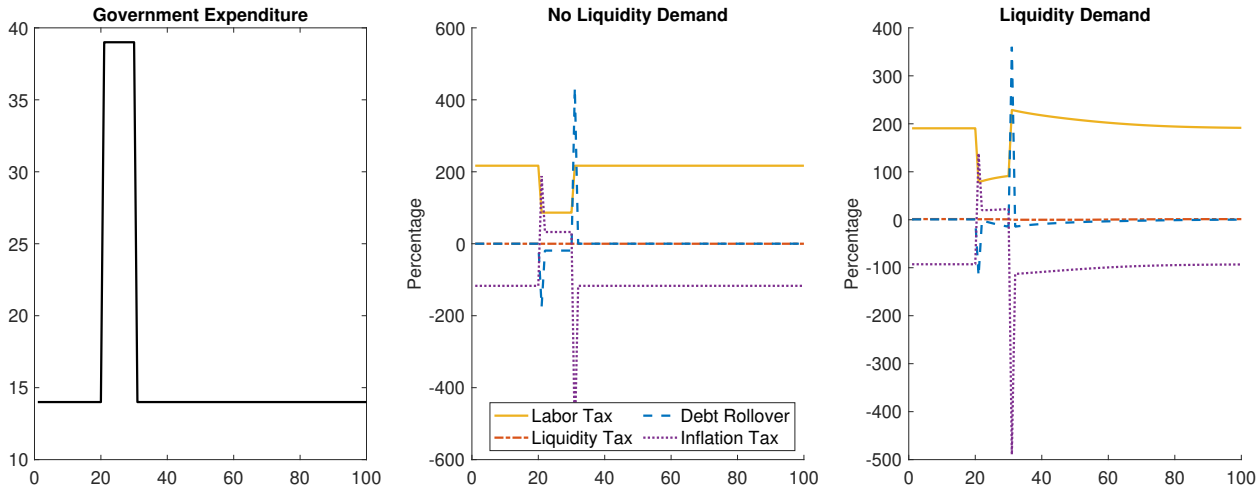



Figure 5: **Tax decomposition with complete markets.** This figure plots the decomposition of taxes for a complete markets model with liquidity demand and without liquidity demand. The left panel plots a one time government expenditure shock, the center panel plots the tax decomposition without liquidity demand, and the right panel plots the tax decomposition with liquidity demand. Prior to the shock there is a long period of low expenditure. Percentages are defined in terms of the government expenditure level $G_t$.

panels plots the magnitude of each tool as a percentage of government expenditure for economies with no liquidity demand and baseline liquidity demand. Prior to the shock there is a long period of low expenditure.

In both economies, labor taxes are the predominate tool to pay for government expenditure during peace time. Labor taxes, as a percentage of government expenditure, exceed 100% because they are also pay for outstanding debt obligations. At the start of a war, the policymaker inflates away much of the debt. During the war a mixture of inflation and labor taxes pay for government expenditure. In order to incentivize households to hold this inflationary debt, the policymaker promises a bonanza at the conclusion of the war. This bonanza is facilitated by a spike in deflation. These jumps in inflation and deflation mimic the lump-sum taxes and transfers of first-best policy.

Liquidity demand does not substantially alter this pattern of taxation. The spike in inflation at the start of wars and the spike in deflation at the end are both smaller. Labor tax income, as a percentage of government expenditure, asymptotes downward during peace time and asymptotes upward during war times. Liquidity tax income is near zero for all states of the world. Therefore optimal policy is not to "eat a free lunch" (Mian et al. (2022)) or "mine the bubble" (Brunnermeier et al. (2022)) by taxing liquidity and *reducing* labor taxes, but rather to satiate liquidity demand ( Blanchard (2019) and Sims (2024)) by *raising* labor taxes.

# 4 Optimal Policy with Noncontingent Debt

This section characterizes the optimal Ramsey policy with incomplete bond markets. With incomplete bond markets, the government issues noncontingent debt which must be paid in full regardless of the state of the world. For households, public debt is risk-free. Liquidity demand markedly in-

creases the optimal debt ratio compared to a model uncalibrated to the convenience yield on public debt. In an economy lacking liquidity demand, the optimal debt level is negative (Aiyagari et al. (2002) and Bhandari et al. (2017a)). In that case, policymakers amass precautionary and buffer stock savings to help insure against future expenditure shocks. In an economy with liquidity demand the optimal debt level is positive (Angeletos et al. (2023)). Policymakers flood the market with safe assets to satiate liquidity demand. Even for conservative calibrations of the liquidity demand parameters in the United States, the satiation motive dominates the savings motive and the average optimal debt level is positive and large. This large debt position is funded with high labor taxes, debt rollovers, and low liquidity taxes. These results are robust to alternative calibrations. The inclusion of liquidity demand helps rationalize recent U.S. public debt levels.

## 4.1 Ramsey Problem

Let $b_s = \frac{B}{N_s}$ be the state-dependent debt ratio. Redefine $\mathscr{B}(B,G,\{N_s,G_s\}) = B\sum_s \Omega_s(G)u_{c,s} + \sum_s \Omega_s w_{b,s} b_s$, $\mathscr{R}_s(B,G,\{N_s,G_s\}) = \frac{u_{c,s}}{(\sum_{s'} \Omega_{s'} u_{c,s'} + w_{b,s'}/N_{s'})}$, $\mathscr{T}_s(N_s,G_s) = u_{c,s}\tau_s(N_s,G_s)N_s$, $\mathscr{Q}_s = w_{b,s}b_s$ and $\mathscr{G}_s(N_s,G_s) = u_{c,s}G_s$ to be the marginal utility adjusted debt, interest rate, labor tax revenue, liquidity tax revenue, and government expenditure. For brevity I refer to these variables as the values of debt, interest rate tax revenue, and government expenditure. For notational convenience I omit their dependence on $(B,G,\{N_s,G_s\})$. The Ramsey planners optimal value function for $t \geq 1$ satisfies the Bellman equation:

$$\begin{aligned} V(\mathscr{B},G) = &\max_{(B,\{N_s,\mathscr{B}_s\})\in\Phi(\mathscr{B},G)} \sum_s \Omega_s(G)[u(N_s-G_s) - v(N_s) + w(\frac{B}{N_s}) + \beta V(\mathscr{B}_s,G_s)] \\ &\text{where } \Phi(\mathscr{B},G) = \{(B,\{N_s,\mathscr{B}_s\}) \in CE(\mathscr{B},G) : \mathscr{R}_s\mathscr{B} + \mathscr{G}_s \leq \mathscr{T}_s + \mathscr{Q}_s + \beta\mathscr{B}_s, \forall s\}. \end{aligned} \tag{12}$$

Where $\Omega_s(G)$ is the probability of state $G_s$ conditional on state $G$ and $CE(\mathscr{B},G)$ is the competitive equilibrium defined in section 2.6. Without liquidity demand, the Ramsey problem (10) is identical to Aiyagari et al. (2002) with risk-aversion or Bhandari et al. (2017a) without price shocks. The construction of this Ramsey problem along with the time 0 Ramsey problem can be found in Appendix C.

## 4.2 Theory of Saving and Satiating

Optimal noncontingent debt policies critically depend on the *savings* motive of the government. Unable to engage in ex-post debt devaluation, the policymaker engages in both precautionary and buffer stock savings to reduce future taxes. Policymakers, worried about a future crisis, engage in precautionary savings to guard against future labor tax increases. Precautionary savings partially cover surprise government expenditure. Policymakers, worried about hitting the natural debt limit, engage in buffer stock savings. At the natural debt limit, labor taxes must cover all government expenditure shocks. To avoid this scenario the policymaker builds up a buffer stock. Together, precautionary and buffer stock savings lead the government to assemble a war-chest of assets.

These governmental savings motive resemble the household savings motive in Bewley-Hugget-Aiyagri incomplete markets model[7].

The size of this war chest depends on the ability of the policymaker to engage in interest rate manipulation. At the extreme, linear consumption utility rules out interest rate manipulation. Policymakers save enough to hit the natural asset limit. At the natural asset limit, the policymaker pays for all government expenditure with interest and keeps labor taxes fixed at zero (Aiyagari et al. (2002)). Concave consumption utility allows the policymaker to manipulate interest rates. Raising interest rates on household's debt mimics lump-sum taxation. Policymakers save enough to insure against fiscal risk with a combination of labor taxes and interest payments (Bhandari et al. (2017a)). This savings level is less than the natural asset limit.

In my model, optimal debt policies also depend on the government's desire to *satiate* liquidity. If non-distortionary taxes are available, the government issues debt until the liquidity tax is zero. This policy is closely related to standard optimal policy in macroeconomics and public finance. Namely the Friedman rule in macroeconomics and the zero-capital tax policy from public finance. Optimal policy in classical monetary models (e.g. Chari and Kehoe (1999)) follows a Friedman-rule: flood the economy with enough money to satiate liquidity demand (Chari et al. (1996)). If government debt, rather than money, provides liquidity services, first-best policy follows a similar rule: flood the economy with enough debt to satiate liquidity demand (Sims (2024)). Optimal policy in neoclassical taxation models recommends a zero capital tax (Atkinson and Stiglitz (1976) and Chari and Kehoe (1999)) for different reasons. Since taxing capital effectively taxes future consumption it violates the uniform commodity taxation rule of Atkinson and Stiglitz (1976). Taxing government bonds by depressing interest rates also taxes future consumptions and is suboptimal.

The optimal debt level is dictated by the relative power of the savings and satiating motives. Their relative power depends on the parameters of the model: a larger Frisch elasticity or intertemporal elasticity of substitution amplifies the savings motive while larger liquidity demand amplifies the satiation motive. At the baseline parameters, the satiation motive trumps the savings motive and the optimal debt ratio target is 42%. In the presence of aggregate shocks, the average optimal debt level in the ergodic distribution is 125%. This average optimal debt level exceeds other estimates in the literature but is closer to recent levels in the United States [8]. This difference reflects the *quantitative* importance of liquidity demand reflected by the convenience yield on pubic debt.

## 4.3 Characterizing Optimal Policy

### 4.3.1 Optimal Debt Target

Figure 6 plots the optimal path of debt, taxes, and interest rates after a seres of low expenditure shocks. The government expenditure level equals .17 for 50 years. Although no aggregate shocks

[7] Shin (2006) similarly contrasted the savings and satiating motive of the government in a two-agent Bewley model.

[8] Models in which the risk-free government debt insurance against aggregate risk, such as Aiyagari et al. (2002), regularly conclude that the optimal debt-to-output level is negative. However, models featuring heterogeneous households and idiosyncratic risk, such as Aiyagari and McGrattan (1998) and Bhandari et al. (2017b), point to positive optimal levels below 100%.

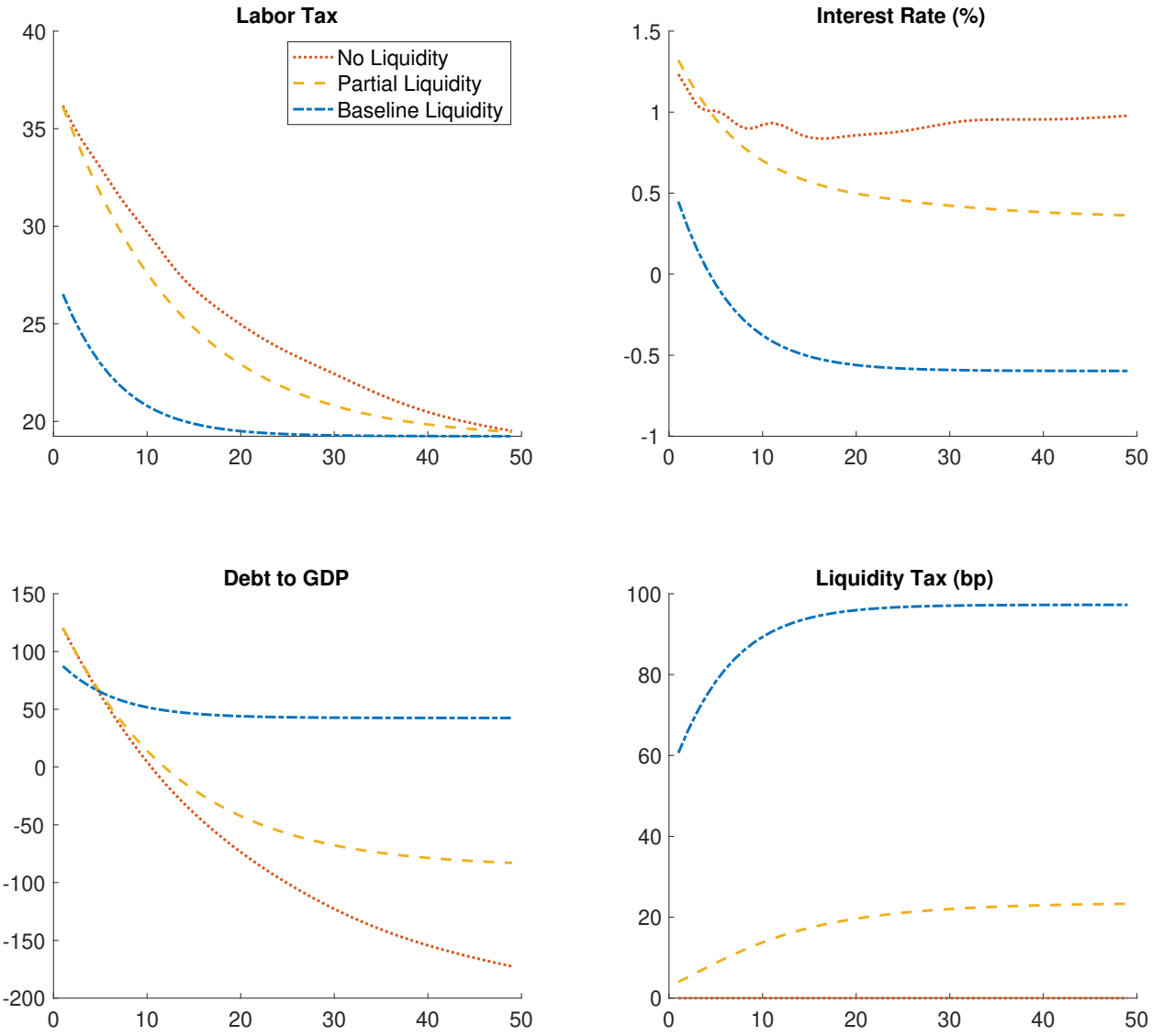



Figure 6: **Optimal policy targets with incomplete markets**. This figure plots the optimal path of debt, taxes, and interest rates after a seres of low expenditure shocks. In the baseline liquidity, partial liquidity, and no liquidity model the demand parameters equal $\{\nu,\phi\}$, $\{.1\nu,.1\phi\}$, and $\{0,0\}$. Debt-to-output begins at 100% for each.

occur during this period the policymaker must allow for fiscal space as a shock could occur next period. This experiment illustrates what policymakers should do during periods of peace. Across all through three models optimal policy calls for reducing the debt level and labor taxes. The optimal debt target is substantially higher when households demand liquidity.

Absent liquidity demand the policymaker quickly reduces the debt and eventually builds up a large asset position. This large asset position acts as precautionary savings against future aggregate shocks. With liquidity demand the policy maker slowly reduces the debt to approximately 42% of output. The incentive to satiate liquidity trumps the incentive to save assets. Liquidity demand raises the optimal debt target and reduces the speed of convergence. Policymaker should reduce

debt to 50% of GDP over a 10 year period if households demand liquidity and over a 5 year period if they do not. The optimal liquidity tax at the optimal debt target is over 100 basis points. Given households demand for liquidity, policymakers should target a higher labor taxes during peacetime. The 100bp liquidity tax at the optimal debt target keeps the interest rate low. If household's demand enough liquidity, the optimal interest rate target is negative. Interest rate suppression allows the government to reduce labor taxes while still running a balanced budget. Though the government must cover a larger debt position, interest rate suppression is large enough to reduce labor taxes.

Policy targets depend on the peacetime expenditure level. Table 3 displays the optimal policy targets for different peacetime expenditure levels. Debt ratios, labor taxes, and interest rates rise with the peacetime expenditure level. Labor tax distortions are amplified by government expenditure. The more output is lost to government expenditure, the more valuable labor becomes. Policymakers partially debt-finance elevated expenditures. More government expenditure leads to more debt financing.

This optimal debt target is greater than in a model without quantitatively realistic liquidity demand (e.g. Bhandari et al. (2017a)) and lower than in a model without aggregate risk (e.g. Aiyagari and McGrattan (1998)). In a quantitative two-agent model with uninsurable aggregate risk, Bhandari et al. (2017a) find that the optimal debt target is approximately 0% of output. The aggregate surplus risk and lack of complete markets leads the savings motive to dominate In a quantitative heterogeneous agent model with uninsurable idiosyncratic risk, Aiyagari and McGrattan (1998) find that the optimal debt target is approximately 60% of output. This level of debt provides enough liquidity in the market for households to insure against idiosyncratic risk. In their model the satiating motive dominates. The optimal debt target advocated in this paper balances the desire to save and satiate.

| | **G = .14** | **G = .17** | **G = .20** | **G = .23** | **G = .26** |
|---|---|---|---|---|---|
| Debt Ratio | 20.96 | 42.48 | 71.02 | 139.42 | 228.19 |
| Labor Tax | 14.78 | 19.24 | 24.95 | 36.48 | 49.38 |
| Interest Rate | -3.62 | -0.60 | 2.80 | 6.81 | 7.64 |
| Liquidity Tax | 117.72 | 97.26 | 70.09 | 12.84 | 0.00 |

Table 3: **Policy Targets.** This table describes the optimal policy targets of the liquidity demand model across different steady-state expenditure. The table presents the debt ratio, labor tax rate, interest rate, and liquidity tax (in basis points) for different expenditure levels. I simulate a model at each expenditure level for 200 years.

### 4.3.2 Optimal Policy Response

Figure 7 plots the optimal policy response from steady-state to a surprise expenditure shock. The figure illustrates optimal policy responses for three models. Specifically, "full liquidity" in which the liquidity demand parameters $(\nu, \phi)$ are set to the baseline calibration in table 1; "partial liquidity" in which the liquidity demand parameters are both 1/10th the baseline calibration; and "no liquidity demand" which sets both liquidity demand parameters to zero. The government expenditure shock starts in period 20 and lasts for 10 years. Prior to the shock there is a long period of

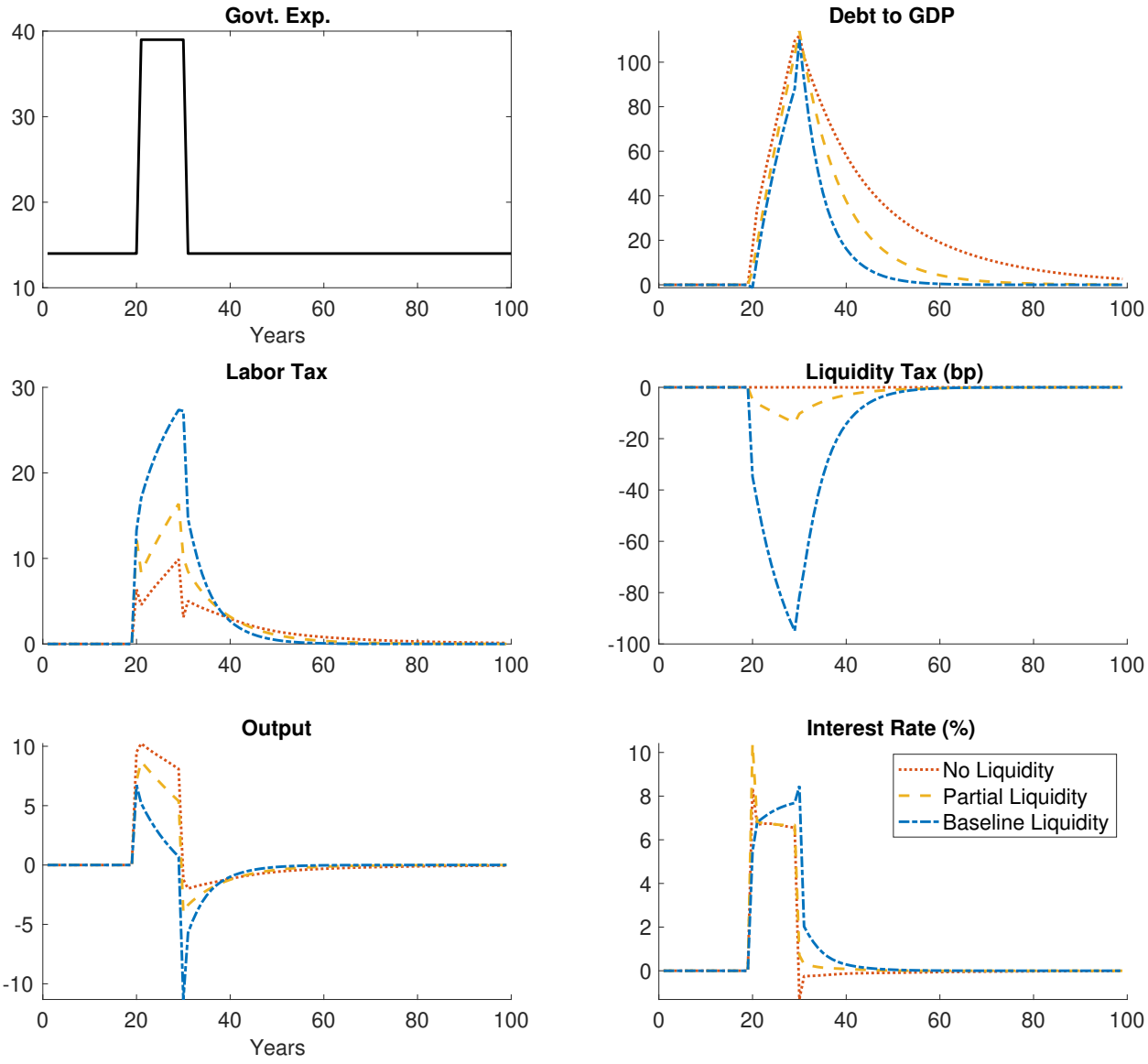



Figure 7: **Optimal policy response with incomplete markets.** This figure plots the optimal policy response to an unforeseen government expenditure shock in the incomplete markets model. In the baseline liquidity, partial liquidity, and no liquidity model the demand parameters equal $\{\nu, \phi\}$, $\{.1\nu, .1\phi\}$, and $\{0, 0\}$. The government expenditure shock starts in period 20 and lasts for 10 years. Prior to the shock there is a long period of low expenditure. The top left panel plots a single government expenditure shock. The remaining panels plot the differences from steady-state for each variable. Output is plotted as the percent difference while the remaining variables are plotted as level differences.

low expenditure. So policy tools begin the simulation at their optimal targets, visualized in figure 6 and table 3. Labor taxes, interest rates and debt-to-output rise while liquidity taxes fall.

Liquidity demand amplifies the rise in labor taxes during wars. Irrespective of the degree of liquidity demand, labor taxes fall during peace times and rise during wars. Liquidity demand dictates the magnitude of wartime rise and the speed of peacetime convergence. By raising the debt burden

being serviced, liquidity demand amplifies the increase in wartime labor taxes. Moreover, liquidity taxes steadily fall as the government builds up debt. Comparing liquidity taxes across economies with varying liquidity demand is complicated by mechanical differences. More liquidity demand systematically leads to higher liquidity taxes for a given level of debt-to-output. Normalizing the liquidity tax by the liquidity tax at the peak of the Laffer curve removes this mechanical effect; facilitating liquidity tax comparison across economies. During wars relative liquidity taxes fall as the government builds up debt. For higher levels of liquidity demand the relative fall is similar. Following the conclusion of the war, labor taxes converge to the optimal peacetime level faster in an economy with liquidity demand. The speed of convergence is higher because the policymaker is more willing to depart from tax smoothing.

Seemingly paradoxically, liquidity demand smooths wartime labor taxes. Persistent expenditure shocks produces positive and negative spikes in labor taxes at the beginning and end of wars [9]. Liquidity demand dampens these spikes. The positive spike in labor taxes at the war's onset spurs a negative spike in consumption facilitating a spike in interest rates. As the government is a net creditor, this positive interest rate spike mimics a lump-sum tax on households. The corresponding negative labor tax spike at the end of the war mimics a lump-sum transfer. Therefore these spikes resemble the inflation tax spikes in the complete markets model (section 3). Manipulating the interest rate to cover expenditure shocks is less efficient in the presence of liquidity demand.

Regardless of liquidity demand, wars are partially debt financed. The onset of a war triggers a gradual debt increase. Aiming to minimize future tax increases the policymaker opts for a partially debt and deficit-financed war. Despite differences in liquidity demand all three economies experience similar increases in debt-to-output during the war. Following the war's conclusion the policymaker steadily reduces the debt. Liquidity demand increases the speed of convergence to the steady-state level.

#### 4.3.3 Optimal Policy Distribution

During peacetime debt ratios tend toward the optimal target of 42%. Surprise crises are partially debt-financed. Together these opposing forces produce an ergodic distribution for the debt ratio. Figure 8 plots the ergodic distribution of labor taxes and debt-to-output. Liquidity demand markedly shifts the distribution of debt upwards. Absent liquidity demand, the debt-to-output converges to a distribution centered at -300% of GDP and tends to fluctuate between -400 and -200%. While in a model with liquidity demand, the distribution of debt-to-output converges to a distribution centered at 125% and tends to fluctuate between 100 and 200%. In this case, debt ratio fluctuations are typically buttressed by the debt Laffer curve peak and the debt satiating level. Though large and persistent crises can push the debt ratio past the debt satiating level and long periods of peace can push it past the debt Laffer curve.

Liquidity demand markedly increases the level and volatility of labor taxes. Absent liquidity demand and risk-aversion, the policymaker builds a war chest of assets and reduces labor taxes to zero to replicate a complete markets outcome (Aiyagari et al. (2002)). Risk aversion leads the policymaker to accumulate less assets and minimize fiscal risk (Bhandari et al. (2017a)) by varying

[9] Optimal taxation policy in a model with capital taxes produces similar spikes albeit for capital taxes (Farhi (2010)).

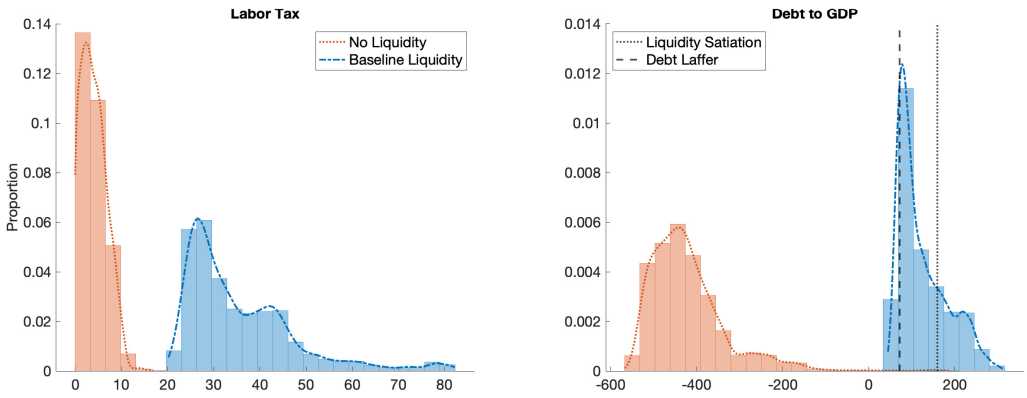



Figure 8: **Optimal policy level with incomplete markets**. This figure plots the distribution of labor taxes and the debt-to-output ratio in the incomplete markets model. I overlay a kernel distribution on each distribution. In the baseline liquidity and no liquidity model the demand parameters equal $\{\nu, \phi\}$ and $\{0, 0\}$. The left and righ panels plots the distribution of labor taxes and debt-to-output ratios. The debt satiation and debt Laffer curve levels plotted in the right panel are only relevant to the model with liquidity demand. There is a 1000 year burnin period prior to the 5000 year simulation.

both the interest rate and labor taxes. Rather than paying for government expenditure with interest on assets and depriving households of liquidity the policymaker opts to tax labor and provide the household liquidity. Though liquidity demand had little impact on averages labor taxes in a complete markets model, liquidity demand notably elevates the entire distribution of labor taxes in an incomplete markets model.

The policymaker utilizes liquidity taxes albeit at a moderate level. Optimal policy prescribes "mining the bubble" to reduce labor taxation (Brunnermeier et al. (2022)). Though optimal liquidity taxation is very low averaging less than 30 basis points. Quantitatively, interest rate suppression of 30 basis points is far below the average historical convenience yield of 70 basis points (Krishnamurthy and Vissing-Jorgensen (2012)). During wars, the aggregate insurance motive of risk-free debt (Aiyagari et al. (2002)) outweighs the desire to tax liquidity. Debt financing the war causes the debt to cross the liquidity satiation point.

The optimal debt level target is determined by the relative welfare value of saving assets and satiating liquidity. The IES $\sigma^{-1}$ and Frisch elasticity $\eta^{-1}$ dictate the value of savings while the liquidity demand parameters $\{\nu, \phi\}$ dictate the value of satiating. A larger Frisch elasticity reduces the volatility of labor taxes while a larger IES reduces the level of labor taxes. A larger Frisch elasticity or IES amplifies the welfare effects of labor-leisure (equation 4) distortions. Moreover a larger IES dampens the policymakers ability to manipulate interest rates. As the scope for interest rate manipulation is minimized the optimal debt level tends toward the natural asset limit. Lower debt levels require lower labor taxes to sustain. Greater liquidity demand will increase the welfare costs of taxing liquidity. This tradeoff is discussed in more detail in Appendix C.6.

## 4.4 Taxation Decomposition

Each year, the policymaker must pay for exogenous government expenditure. There are three tools at the policymaker's disposal: (1) labor taxes (2) liquidity taxes and (3) debt rollover. The policymaker can tax labor income, tax government debt's liquidity services, or issue new debt. Since debt is noncontingent, there is no ex-post devaluation and thus no inflation taxes.

$$G_t = \overbrace{\tau_t N_t - T_t}^{\text{Labor Tax Rev.}} + \underbrace{\omega_t b_t}_{\text{Liquidity Tax Rev.}} + \underbrace{\left(\frac{B_t}{R_t^{CS}} - B_{t-1}\right)}_{\text{Debt Rollover}} \tag{13}$$

As in subsection 3.4, I rearrange the government budget equation (8) to decompose the government expenditure across these three tools (equation 13): the net labor tax revenue $\tau_t N_t - T_t$ , the liquidity tax revenue $\omega_t b_t$, and the debt rollover $\frac{B_t}{R_t^{CS}} - B_{t-1}$ as the value of debt rollover. Because inflation taxation is ruled out, this decomposition is now over three policy tools rather than four. Since debt is noncontingent liquidity taxes revenue is based on the liquidity demanded this year rather than the expected demand next year. Again, I use the consumption smoothing interest rate $R_t^{CS}$ rather than the prevailing interest rate $R_t$ in defining the debt rollover to differentiate between liquidity taxation and debt rollover.

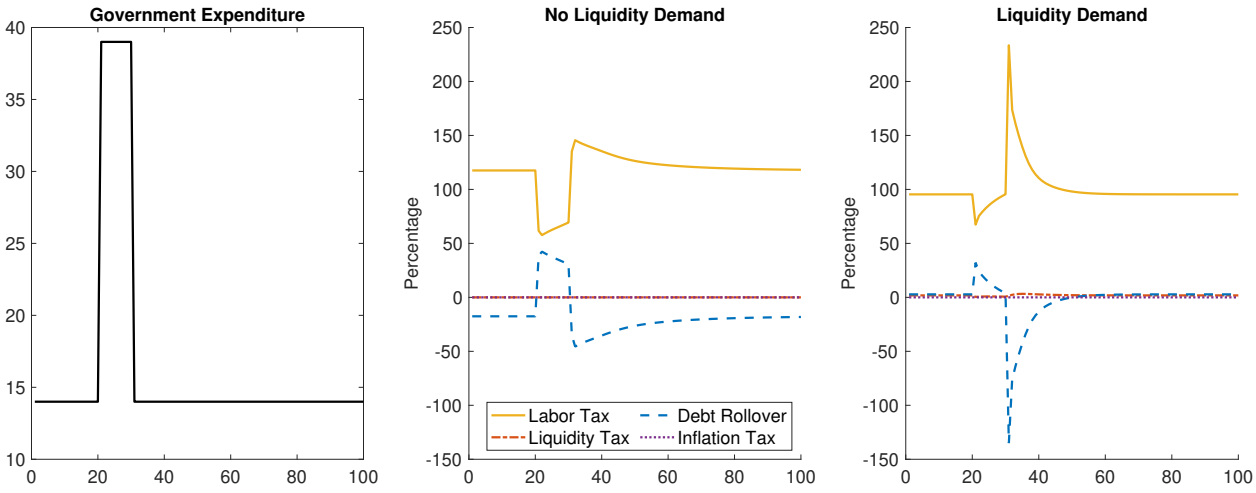



Figure 9: **Tax decomposition with incomplete markets.** This figure plots the decomposition of taxes for a incomplete markets model with liquidity demand and without liquidity demand. The left panel plots a one time government expenditure shock, the center panel plots the tax decomposition without liquidity demand, and the right panel plots the tax decomposition with liquidity demand. Prior to the shock there is a long period of low expenditure. Percentages are defined in terms of the government expenditure level $G_t$.

This decomposition, visualized in Figure 9, allows comparison of each tools importance across states of the world. The left panel plots the government expenditure shock, and the middle and right panels plots the magnitude of each tool as a percentage of government expenditure for economies with no liquidity demand and baseline liquidity demand. Prior to the shock there is a long period of low expenditure.

In both economies, labor taxes are the predominate tool to pay for government expenditure during peace time. Since labor taxes also pay for debt issued last year they can exceed 100% of government expenditure. At the start of a crisis, the policymaker rolls over the debt rather than inflate it away as she would with contingent debt. Consistent with Barro (1979), the policymakers desire to smooth taxes leads debt and labor taxes to permanently increase following a government expenditure shock. Prolonged crises make continuing debt rollovers ever more costly and push the policymaker to resort to increasingly more labor taxation. The conclusion of the crisis causes the policymaker to steadily reduce labor taxes and the debt level.

Liquidity demand does not substantially alter this pattern of taxation, though it introduces a tertiary taxation tool. During peace time, liquidity taxes are utilized to reduce labor taxes. Therefore optimal policy calls for "eating a free lunch" (Mian et al. (2022)) or "mining the bubble" (Brunnermeier et al. (2022)) by taxing liquidity and *reducing* labor taxes during peace times not crises.

## 4.5 Optimal and Actual Debt Policy

Optimal debt ratios resemble actual debt ratios in advanced countries. According to the IMF, the average debt level in advanced economies has risen from 50% in the 1980s to 115% in the 2010s. As of 2023, public debt to GDP sits at 93% in the European Union, 100% in the United Kingdom, 120% in the United States, and 260% in Japan. Only two advanced economies maintain a negative net debt position - Norway and Luxembourg. The 124% average optimal debt ratio in the model is similar in magnitude to these actual debt levels.

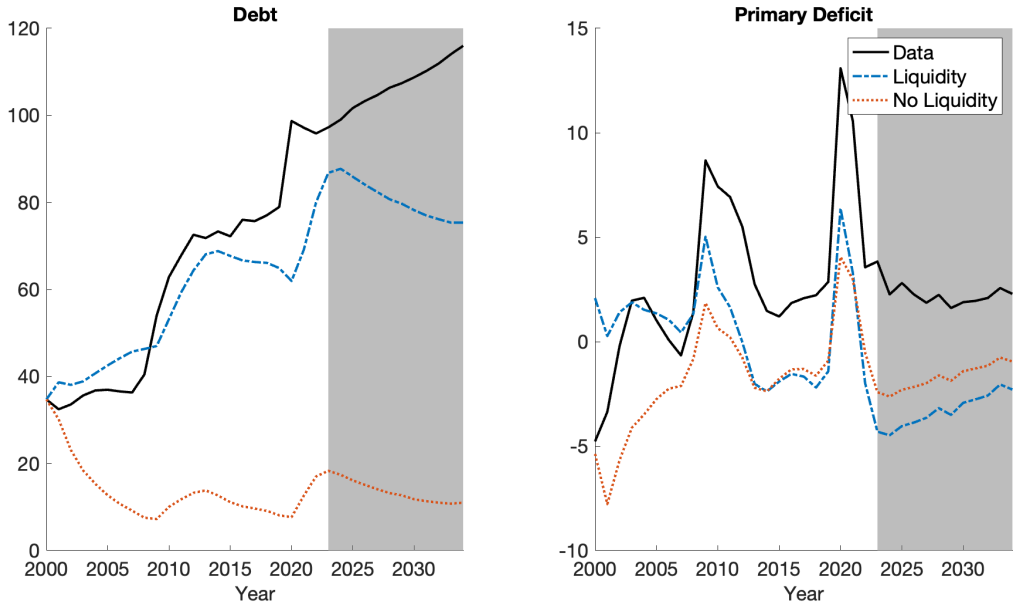



Figure 10: **Recent debt and primary deficit ratios.** This figure plots the actual and optimal debt and primary deficit ratios in the United States since 2000. Actual debt is the gross debt held by the public (FYGFDPUB in FRED). Optimal policy begins in 2000 with the same debt ratio and expenditure level as the actual history.

Although the average optimal debt ratio resembles the current debt ratio, recent debt policy was overly reliant on debt financing. Figure 10 plots the actual and optimal U.S. debt and primary deficit ratios since 2000. The optimal policy begins in the year 2000 with the same debt ratio and expenditure level as the United States [10]. The quantitative model used for this exercise is nearly identical to the baseline model with noncontingent debt, except that this model rules out government asset accumulation. Fiscal stress from the Great Financial Crisis and the Covid Pandemic expanded the debt. In both instances policymakers relied too heavily on debt-financing. As a percentage of GDP, primary deficit ratios were 5% too high during the former and 7% too high during the latter. Between crises policymakers failed to reduce the debt. By 2023, this over-reliance on debt-financing pushed debt ratios 10% too high.

Although over-reliant on debt, recent policy had moderate welfare impacts. To gauge the welfare impacts, I compare the continuation value $V(\cdot, G_{2023})$ of the actual debt $\mathscr{B}^{act}_{2023}$ to the optimal debt $\mathscr{B}^{opt}_{2023}$ at 2023 expenditure levels given the history of expenditure since 2000. Reducing debt to the optimal level increases welfare $V(\mathscr{B}^{opt}_{2023}, G_{2023}) - V(\mathscr{B}^{act}_{2023}, G_{2023}) > 0$. To have a sense of scale, I compare this difference to the difference between optimal and the worst case: $V(\mathscr{B}^{opt}_{2023}, G_{2023}) - \min_{\mathscr{B}} V(\mathscr{B}, G_{2023})$. Reducing the debt from the actual amount to the optimal amount would increase welfare by 5% of this maximum welfare distance.

According to the model, observers should worry about the projected rise in public debt. While recent debt policy resembles optimal policy, debt ratios are well above the optimal target. Moreover, debt ratios are projected to increase, not decrease, over the next 10-20 years (*Options for Reducing the Deficit: 2021 to 2030* (2020)). Policymakers should be running 2% surpluses not 2% deficits as projected. The United States was hit with two large fiscal crisis over the last 15 years. The Global Financial Crisis and Covid Pandemic put substantial stress on the fiscal budget and expanded the debt. Increasing the debt during crises is optimal; maintaining this debt during peacetime is not. Therefore, given the expected path of government expenditure, policymakers should aim to reduce debt to 75% of GDP over the next 10 years. If debt continues on its projected path, there will be substantial welfare losses. I use the same formula for welfare comparisons in 2034 as I used for 2023. Failure to reduce the debt to optimal would reduce welfare by 12% of the maximum welfare difference.

Although elevated, current and projected debt levels do not threaten fiscal sustainability. The natural debt limit is 269% of GDP. Hitting the natural debt limit requires an enormous crisis. Following a decade long crisis, on par with World War II, the United States would still have fiscal space. To see this, suppose the government maintains a peacetime debt level of 100%. Figure 7 makes clear that a surprise decade long war would increase the debt ratio by 100% to 200%. At this point the government would still have fiscal space. Currently high debt levels in the United States do not threaten fiscal capacity.

| Model | Mean | Median | Std. Dev. | Target | Debt Limit |
|---|---|---|---|---|---|
| No Liquidity | -419.96 | -436.48 | 90.23 | -229.30 | 268.98 |
| Partial Liquidity ($\nu/5, \phi/5$) | 19.66 | -9.02 | 82.61 | -86.38 | 268.98 |
| Baseline | **124.12** | 103.08 | 57.05 | **42.48** | 268.98 |
| Mian et al. (2022) | 163.81 | 150.25 | 40.42 | 96.13 | 268.98 |
| Jones (2024) | 188.06 | 184.86 | 38.91 | 67.75 | 272.10 |
| Income Effects (IES = .8) | 155.28 | 123.96 | 80.92 | 42.25 | 367.96 |
| Substitution Effects (IES = 1.4) | 48.50 | 39.05 | 23.91 | 8.41 | 123.52 |
| More Elastic Labor (Frisch = 1) | 84.75 | 75.37 | 34.67 | 11.66 | 162.14 |
| Less Elastic Labor (Frisch = .25) | 149.72 | 114.92 | 79.62 | 56.94 | 417.66 |
| Less Labor Disutility ($\Xi = 1$) | 148.56 | 120.82 | 70.03 | 52.94 | 371.26 |
| More Patient ($\beta = .98$) | 153.60 | 120.09 | 87.01 | 50.15 | 672.44 |
| Heightened Crisis Prob. ($\bar{\rho} = .75$) | 116.77 | 105.25 | 79.65 | -26.50 | 268.98 |
| Big Crisis ($\bar{G} = .60$) | 10.41 | -1.61 | 30.59 | -27.84 | 99.20 |

Table 4: **Alternative Calibrations.** This table describes the optimal debt policy for different parameter calibrations. The first block present alternative liquidity demand calibrations. The second block present alternative preference calibrations. And the third block present different shock processes.

## 4.6 Robustness

The optimal debt levels and targets are sensitive to liquidity demand calibrations and robust to alternative preference calibrations. Table 4 describes key statistics of the optimal debt policy for alternative calibrations. The first block present alternative liquidity demand calibrations. The second block present alternative preference calibrations. And the third block present different shock processes. I simulate 200 years of low government expenditure ($G = .17$) to calculate the optimal debt target.

Optimal debt policy critically depends on the demand for liquidity. Both Mian et al. (2022) and Jones (2024) directly estimate the demand for liquidity through causally identified surprise debt issuance. Mian et al. (2022) use the 2022 Georgia Senate runoff as a natural experiment for surprise debt issuance. Democrats had a 50% chance of winning and controlling the senate. Their victory in Georgia facilitated a nearly $2 Trillion debt-financed stimulus. Jones (2024) uses high frequency identification of surprise debt issuance at weekly Treasury auctions. Both papers estimated significantly stronger demand for liquidity than used to calibrate the baseline model. Consequently, the average optimal debt levels and optimal debt targets are significantly higher. The liquidity demand estimated by Jones (2024) is strong enough to raise the debt limit, albeit a small amount. Therefore the optimal debt levels advocated by the model are likely conservative estimates.

Household preference parameters also affect optimal debt policy. If income effects dominate substitution effects, optimal debt levels should be higher. The opposite is true for substitution effects. Microeconomic empirical studies typically estimates the IES to be below 1 while macro studies

[10]These optimal policy paths differs from the paths in figure 1. Optimal policy paths depends on the history of shocks and the initial conditions, which differ across these figures. Figure 1. makes clear that starting in 1935 produces similar results.

estimate the IES to be above 1 (Havránek (2015)). Less elastic labor supply leads to higher optimal debt targets and levels. Micro estimates typically estimate households' labor supply to be less elastic than macro studies (Chetty et al. (2011)). More patient households allow for more fiscal expansion. Patient households demand a lower interest, making debt issuance less costly. More patient households lead to larger optimal debt targets and levels.

As the likelihood and magnitude of war increases, the optimal debt levels and targets decrease. Big crises and heightened crisis probabilities significantly reduce the optimal target debt. The government expenditure process in the baseline model is already a conservative estimate: World War II arrives every 20 years.

# 5 Optimal Policy with Stochastic Liquidity Demand

I solve for the optimal Ramsey policy in an extension of the baseline model with stochastic liquidity demand. Fluctuating liquidity demand introduces interest rate risk. I calibrate these fluctuations to closely match the historical interest rate spread between Treasury bonds and less liquidity AAA corporate bonds. In order to focus on interest rate risk government expenditure is constant. With noncontingent bonds the average optimal debt level is 151% of output. Following a rise in liquidity demand, optimal policy reduces labor taxes and real interest rates and issues debt.

## 5.1 Theory of Liquidity Demand Shocks

The model in this sections builds on the baseline model in Section 2. Details of the model in Appendix D. Broadly, this model sets aside surplus risk to focus on interest rate risk. I abstract from surplus risk by setting government expenditure to a constant low level $G_t = G^{low}\ \forall t$. I introduce endogenously stochastic interest rate risk through liquidity shocks. These liquidity shocks alter the household's consumption-savings decision and government's optimal Ramsey policy.

Let the stochastic liquidity demand be modeled as,

$$\nu_t = (1-\rho)\nu + \rho\nu_{t-1} + \varepsilon_t, \tag{14}$$

where the shocks $\varepsilon_t$ are normally distributed $\varepsilon_t \sim N(0, \sigma^{\nu})$. This AR(1) process closely matches the history of interest rates on Treasury bonds. Kekre and Lenel (2021) utilize a similar process to model safety shocks. Liquidity shocks alter the household savings decision. In particular these fluctuations in liquidity produce a *stochastic liquidity-adjusted Euler equation*,

$$\frac{1}{R_t} = \frac{1}{R_t^{LS}} + \beta \sum_{s^{t+1}} \frac{\Omega(s^{t+1}|s^t)}{u_{C,t}N_{t+1}}[\nu_t - \phi \sinh^{-1}(b_t)]. \tag{15}$$

The stochastic liquidity-adjusted Euler equation (15) resembles the liquidity-adjusted Euler equation (5) in the baseline model. The only difference being the stochastic liquidity spread parameter

$\nu_t$, which captures household's varying demand for liquidity. For a fixed debt-to-output level $b_t$ the convenience yield $R_t^{LS} - R_t$ is stochastic.

Liquidity demand fluctuations also affect the government's problem. Fluctuating liquidity demand alters the natural asset limit and the debt Laffer curves. The natural asset limit is the maximal asset limit at which the government can pay for future expenditure at the minimum interest rate. Governments earning low interest rates on their savings require more assets. Since interest rates are stochastic the required asset level varies with the degree of liquidity demand. If positive liquidity shocks push the interest rate above the minimum, the government can remain at the natural asset limit and rebate the excess return on its assets to the household via a transfer.

The debt Laffer curve is now stochastic, meaning that the peak of the debt Laffer curve and the liquidity satiating point vary with the state of the world. Keeping liquidity completely satiated following a rise in liquidity demand requires debt issuance.

Since public debt is noncontingent, first-best debt policy aims to satiate *expected* liquidity demand. Too much debt causes excessive labor taxation in low liquidity demand states. Too little debt causes excessive liquidity taxation in high liquidity demand states. The persistence of liquidity demand shocks implies that positive shocks raise the expected level.

## 5.2 Ramsey Problem

Define $b_s = \frac{B}{N_s}$ to be the state-dependent debt-to-output ratio. Redefine $\mathscr{B}(B, \nu, \{N_s, \nu_s\}) = B\sum_s \Omega_s(\nu)u_{c,s} + \sum_s \Omega_s(\nu)w_{b,s}(\nu_s)b_s$, $\mathscr{R}_s(B, \nu, \{N_s, \nu_s\})) = \frac{u_{c,s}}{(\sum_{s'} \Omega_{s'} u_{c,s'} + w_{b,s'}(\nu_{s'})/N_{s'})}$, $\mathscr{T}_s(N_s, \nu_s) = u_{c,s}\tau_s(N_s)N_s$, and $\mathscr{G}_s(N_s, \nu_s) = u_{c,s}G$ to be the marginal utility adjusted debt, interest rate, tax revenue, and government expenditure. For brevity I refer to these variables as the values of debt, interest rate tax revenue, and government expenditure. For notational convenience I omit their dependence on $(B, \nu, \{N_s, \nu_s\})$. The Ramsey planners optimal value function for $t \geq 1$ satisfies the Bellman equation:

$$\begin{aligned} V(\mathscr{B}, \nu) = &\max_{(B, \{N_s, \mathscr{B}_s\}) \in \Phi(\mathscr{B}, \nu)} \sum_s \Omega_s(\nu)[u(N_s - G_s) - v(N_s) + w(\frac{B}{N_s}, \nu_s) + \beta V(\mathscr{B}_s, \nu_s)] \\ &\text{where } \Phi(\mathscr{B}, \nu) = \{(B, \{N_s, \mathscr{B}_s\}) \in CE(\mathscr{B}, \nu) : \mathscr{R}_s\mathscr{B} + \mathscr{G}_s \leq \mathscr{T}_s + \mathscr{Q}_s + \beta\mathscr{B}_s, \forall s\}. \end{aligned} \tag{16}$$

Where $\Omega_s(\nu)$ is the probability of state $\nu_s$ conditional on state $\nu$ and $CE(\mathscr{B}, \nu)$ is the competitive equilibrium defined in section 2.6. The construction of this Ramsey problem along with the time 0 Ramsey problem can be found in Appendix D. This model can be seen as a generalization of Sims (2024) (Section 5) without the assumption of perfect foresight.

## 5.3 Calibrating Liquidity Shocks

The liquidity demand spread parameter follows an AR(1) process, $\nu_t = (1-\rho)\nu + \rho\nu_{t-1} + \varepsilon_t$. By log-linearizing the stochastic liquidity adjusted Euler equation (15) around steady state, I can write the convenience yield $r_t^{LS} - r_t$ in terms of the stochastic liquidity demand $\nu_t$ and the debt-to-output level $b_t$: $\frac{Y}{C}(r_t^{LS} - r_t) = \nu_t + \phi \sinh^{-1}(b_t)$. I use the spread between AAA corporate bonds $r_t^{AAA}$ and long-maturity Treasury bonds $r_t^{Tres.}$ as a proxy for the convenience yield $r_t^{LS} - r_t$. AAA corporate bonds are similarly safe to Treasury bonds but do not offer the same liquidity services. I calibrate the stochastic properties of $\nu_t$ to match the AAA/Treasury spread given historical debt-to-GDP levels. Table 5 lists the calibrated parameters and corresponding targets.

| Parameter | Description | Value | Basis Points | Target |
|---|---|---|---|---|
| $\nu$ | Average interest spread on liquid assets | .0192 | 128 | Avg. residual convenience yield |
| $\rho$ | Persistence of liquidity shocks | .685 | N/A | Autocorrelation of residual convenience yield |
| $\sigma^\nu$ | Standard deviation of interest rate shocks | .0042 | 28 | Std. dev. of residual convenience yield |
| $\phi$ | Semi-elasticity of interest rate spread with public debt | .0154 | 103 | Convenience yield |

Table 5: **Liquidity Demand Model Calibration.**

Let the residual convenience yield be the convenience yield unexplained by the debt-to-GDP level. Conditional on the debt level, I set $\nu$ to .0192 to match the average residual convenience yield, $\rho$ to .685 to match the autocorrelation of the residual convenience yield, and $\sigma^\nu$ to .2828 to match the standard deviation of the residual convenience yield. This parameterization approximates the historical convenience yield well ($R^2 = .60$). The average convenience yield in the data is 82 basis points in the model and the data, standard deviation is 45 basis points in the data and 35 basis points in the model, skewness is 68 basis points in the data and 89 in the model, and autocorrelation is .75 in the data and .31 in the model.

Figure 11 illustrates these calibrated liquidity shocks. The top panel plots the historical debt-to-GDP level, the middle panel plots the estimated liquidity shocks, and the bottom panel plots the actual and estimated convenience yield. Decades of high debt, for instance the 1940s and 1950s, lead to low convenience yield (Krishnamurthy and Vissing-Jorgensen (2012)). However the debt levels only explains some of the movement in convenience yields. Stochastic liquidity demand appreciably improves the fit ($R^2 = .19$ vs. $R^2 = .60$) compared to a model with static liquidity demand. Unlike the static model, the stochastic liquidity demand model closely matches major liquidity demand episodes including the Great Depression, Volcker Disinflation, and Great Financial Crisis.

## 5.4 Characterizing Optimal Policy

### 5.4.1 Optimal Policy Response

Figure 12 plots the optimal policy response from steady-state to a surprise liquidity shock. The liquidity shock starts in period 20 and lasts for 10 years. Prior to the shock there is a long period of low liquidity demand. Each year the policymaker is uncertain if the liquidity crisis will persistent another year. On impact labor taxes, interest rates, and the debt ratio fall while liquidity taxes rise.

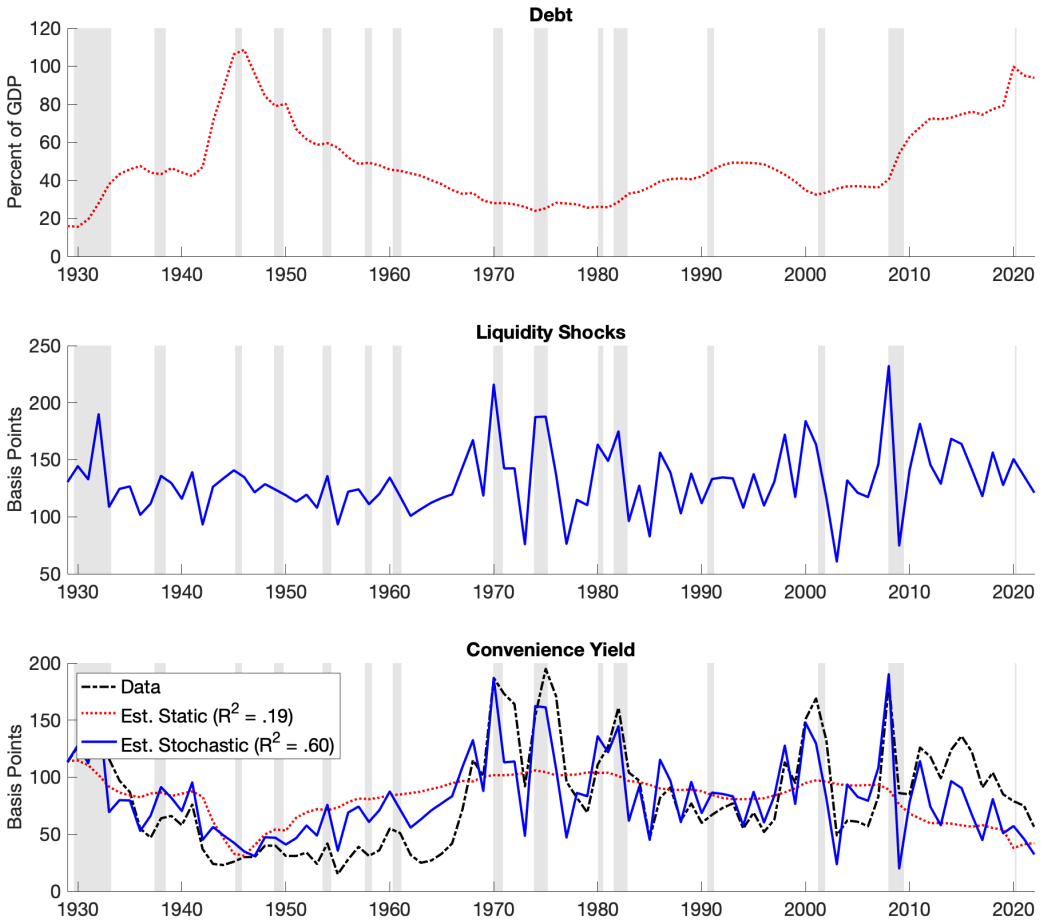



Figure 11: **Calibrated liquidity shocks.** This figure plots the estimated liquidity shocks and the estimated convenience yield. The top panel plots plots the historical debt-to-GDP level, the middle panel plots the estimated liquidity shocks in basis points, and the bottom panel plots the actual and estimated convenience yield in basis points. The static model features a constant spread parameter $\nu$ while the stochastic model allows for time-varying spread parameter $\nu_t$.

Throughout the crisis labor taxes, liquidity taxes, interest rates, and debt ratio rise while liquidity taxes fall. Liquidity crises are a boon to the government budget.

Policymakers raise the debt ratio in response to a liquidity demand shock. Because debt is non-contingent, on impact the debt level is unchanged. However output jumps in response to the labor tax cut, so the debt ratio falls slightly at the onset. The debt ratio jumps up at the conclusion of the crisis through a similar mechanical output effect. During the liquidity crisis policymakers gradually issue debt to satiate liquidity demand. The debt level does not jump, but rather increases slowly, because policymakers hedge against the possibility of the liquidity crisis ending. After the liquidity crisis abates, policymakers slowly lower the debt level. Debt converges slowly outside the crisis so the policymaker can smooth labor taxes.

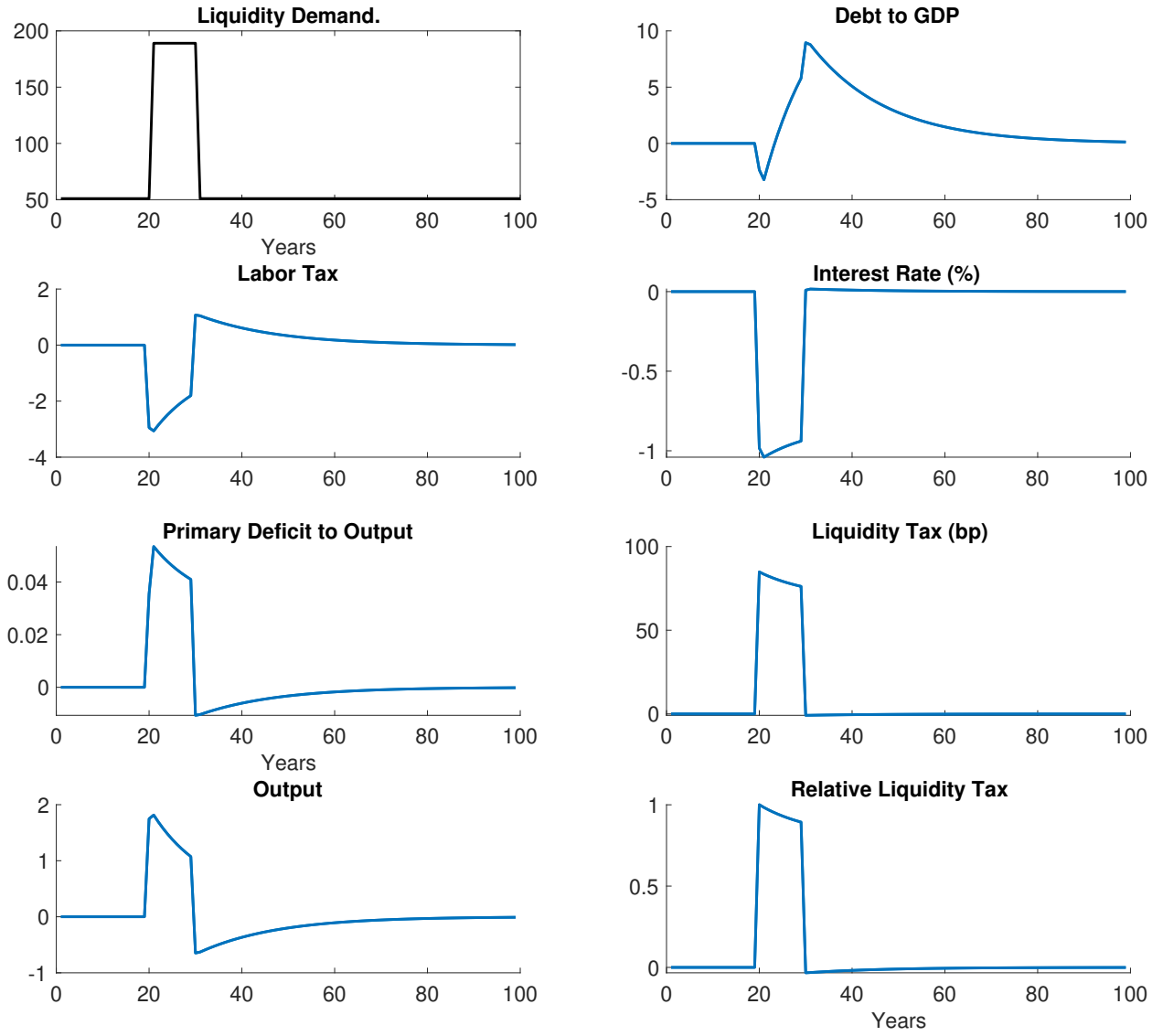



Figure 12: **Optimal policy response to liquidity shocks.** This figure plots the optimal policy response to an unforeseen liquidity demand shock. The liquidity demand shock begins in year 20 and lasts for 10 years. Prior to the shock there is a long period of low liquidity demand. The top left panel plots a single liquidity demand shock. The remaining panels plot the differences from steady-state for each variable. Output is plotted as the percent difference while the remaining variables are plotted as level differences.

The policymaker takes advantage of the reduced financing costs to lower labor taxes. Greater liquidity demand induces lower interest payments. These low interest payments allow the government to reduce labor taxes. During the liquidity crisis labor taxes gradually rise as debt expands, but remain below the pre-crisis level. Labor tax cuts spur a jump in output. While policymakers partially debt-finance liquidity crises, they also resort to liquidity taxation. About half of the liquidity shock (100 bp) manifests as a rise in the liquidity tax (50 bp). Completely satiating liquidity would require a substantial increase in the debt. Policymakers forego this increase to reduce future labor taxes.

On impact, liquidity shocks lower interest rates. The sudden demand for liquidity increases the price of safe assets and lowers the interest rate. Since debt is risk-free, it does not move on impact. Therefore by the stochastic liquidity-adjusted Euler equation (15) a surprise liquidity shock lowers the interest rate. The rising debt level increases interest payments and lowers the convenience yield – together these forces push the interest rate up.

### 5.4.2 Optimal Policy Distribution

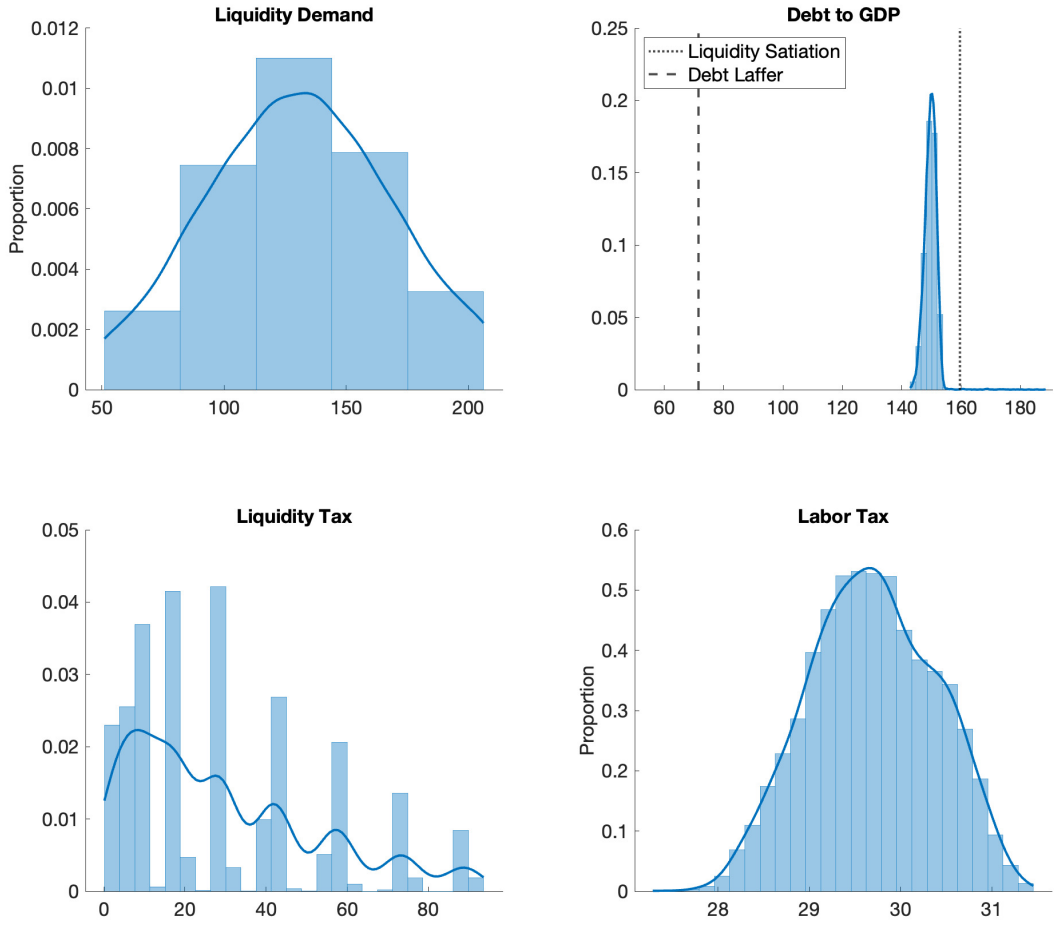



Figure 13: **Optimal policy level with liquidity shocks.**. This figure plots the distribution of liquidity shocks, labor taxes, liquidity taxes, and the debt-to-output ratio in the stochastic liquidity demand model. I overlay a kernel distribution on each distribution. There is a 1000 year burnin period prior to the 5000 year simulation.

Figure 13 plots the ergodic distribution of key policy variables. For the static baseline parameters, I plot liquidity satiation (dotted line) and debt Laffer curve peak (dashed line) in the debt-to-GDP panel. Mean liquidity demand is 130 basis points and fluctuates greatly (s.d. 42 basis points). At

the extremes, positive and negative liquidity shocks shift between 50 to 200 basis points – an 150 basis point difference. Despite large swings in the demand for liquidity, the optimal debt level is high. Interest rates and liquidity taxes absorb most of the variation in liquidity demand. While the debt ratio and labor taxes remain relatively constant.

Debt levels are centered at 151% of GDP and fluctuate very little. (s.d. 2.5%). The liquidity demand process is not particularly persistent ($\rho = .69$). Therefore liquidity shocks dissipate quickly. Since the policymaker satiates expected liquidity, not current liquidity, the optimal debt level is relatively constant.

Moreover, because government expenditure is constant, total government expenditure remains relatively constant. This allows labor taxes to remain fixed. Labor taxes average 30% and fluctuate little (s.d. 1 %). However, regardless of liquidity crises, government expenditure and debt payments are labor tax-financed.

Rather than impact the debt level or labor taxes, the 42 basis point jumps in liquidity demand manifest as liquidity tax jumps and interest rate drops. Interest rates average 4.9% and fluctuate moderately (s.d. 30 basis points). Liquidity taxes average 33 basis points and fluctuate substantially (s.d. 25 basis points). Their combined variation (55 basis points) is large enough to absorb the liquidity demand shocks.

# 6 Optimal Policy with Strategic Default

The average optimal debt ratios prescribed by the surplus and liquidity risk models, Sections 4 and 5, exceed 125%. At these elevated debt ratios policymakers could elect to default. How robust are these optimal policies to default risk? Default risk could raise interest rates and counteract the liquidity premium. I find that optimal debt policy is robust to default risk. Liquidity demand introduces an additional cost to default: a liquidity catastrophe. During a liquidity catastrophe, triggered by default, households are barred from saving and receiving liquidity benefits. This cost is substantial enough that despite the elevated debt, policymakers will almost never default. The default premium is small.

I solve for optimal policy in an extension of the baseline model with strategic default. Defaulting affords policymakers the opportunity to reduce the debt burden and labor taxes. Repaying allows policymakers to retain financial market access and avoids declines in output. If households demand liquidity, repayment also avoids a liquidity catastrophe. I calibrate a quantitative model to match empirical estimates of default costs. With realistic liquidity demand policymakers default less than 1% of the time despite an 120% average debt ratio. The endogenous debt limit in the model exceeds 300% of GDP. Average and target optimal debt levels resemble debt levels in models without default. The liquidity premium lowers interest rates by 49bp, while the default premium raises interest rates by 22bp. Even in a model devoid of ad hoc default costs, the threat of a liquidity catastrophe allows policymakers to sustain debt[11].

[11] An additional cost left out of this model is the potential loss of "exorbitant privilege." Choi et al. (2024) find that the perceived cost of losing this privilege affords the U.S. extra fiscal space. Including this cost in my model would strengthen the results.

In Appendix E.1, I outline the household and government's decisions, and the equilibrium definition.

## 6.1 Policymaker's Problem

In this section I represent the policymaker's problem as a recursive equilibrium. Let $V(B,N,G)$ be the value of financial access, $V^R(B,N,G)$ be the value of repaying debt, and $V^D(B,G)$ be the value of defaulting. Output $N$ is included as a state variable because the policymaker sets out a taxation plan one period in advance. The labor Laffer curve creates a one-to-one mapping between taxes and output $\tau(N)$. Therefore the policymaker's state-contingent tax plan is isomorpic to a state-contingent output plan. The value of financial access is given by,

$$V(B,N,G) = \max_{\delta \in \{0,1\}} (1-\delta)V^R(B,N,G) + \delta V^D(B,G). \tag{17}$$

Where$\delta \in \{0,1\}$ is policymakers default decision. Only policymakers can default on debt, households must repay[12]. Default is only possible when $B > 0$. The equilibrium default decision $\delta(B,N,G) = \mathbb{1}[V^D(B,G) > V^R(B,N,G)]\mathbb{1}[B > 0]$ of the policymaker depends on the value of repaying $V^R(B,N,G)$ and defaulting $V^D(B,G)$.

The value of defaulting $V^D(B,G)$ satisfies the following Bellman equation,

$$\begin{aligned} V^D(B,G) = &\max_{N \in \Phi^D(B,G),\ N_s \in CE(\psi B, G_s)} u((1-\kappa)N - G) - v(N) + w(0) \\ &+ \beta \sum_s \Omega_s [\lambda V^D(B,G_s) + (1-\lambda)V(\psi B, N_s, G_s)] \\ &\text{with } \Phi^D(B,G) = \{N \in CE(B,G) : 0 \leq u_C C - v_N N\}. \end{aligned} \tag{18}$$

Where $CE(B,G)$ is the set of competitive equilibrium, $\kappa$ is the output loss during financial autarky, $(1-\lambda)$ is the probability of regaining market access, and $(1-\psi)$ is the haircut on debt. Policymakers lose market access for stochastic number of periods when they default. Default disrupts the economy, generating an output wedge $\kappa$. Upon regaining financial market access, policymakers must repay $\psi$ percent of the previous debt. Equilibrium output during a default period $N^D(B,G)$ is determined by the government's budget, expressed in primal form by equation $\Phi(B,G)$. The government must set taxes high enough to pay for government expenditure. The value of default does not depend on output $N$ because the defaulting policymaker can deviate from the previous taxation plan.

The value of repaying $V^R(B,N,G)$ satisfies the following Bellman equation,

[12]Chari and Kehoe (1993) consider a model in which both policymakers and households can default.

$$
\begin{aligned}
V^R(B,N,G) = \max_{(B',N_s)\in\Phi^R(B,N,G)} \; & u(N-G) - v(N) + w(b) + \beta \sum_s \Omega_s V(B',N_s,G_s) \\
\text{with } \Phi^R(B,N,G) = \{(B',N_s) \in CE(B,G) : \; & Bu_C \leq u_C C - v_N N \\
& + \beta B' \sum_s \Omega_s (1-\delta(B',N_s,G_s)[u_{C,s} + w_{b,s} b_s]\}
\end{aligned} \tag{19}
$$

Where $B'\sum_s \Omega_s(1-\delta(B',N_s,G_s)[u_{C,s}+w_{b,s}b_s]\}$ is the value of debt issuance, $u_C C - v_N N$ is the value of the primary surplus, and $Bu_C$ is the value of previously issued debt. Value of debt issuance is the interest-rate inclusive debt issuance $\frac{B'}{R}$. Value of the primary surplus is the primary surplus $\tau(N)N - G$. All three are expressed in units of marginal consumption utility $u_C$.

### 6.1.1 Default Decision and Debt Limit

Each year policymakers decide whether to repay their outstanding debt or default. Indebted policymakers will default if the value of defaulting is greater than the value of repaying, i.e. $V^D(B_t,G_t) > V^R(B_t,N_t,G_t)$. There are benefits and costs to defaulting. Default allows policymakers to reduce current taxes and the future debt burden. However default triggers a recession and liquidity crisis that can last for many years. To first approximation this tradeoff can be written as an inequality,

$$
\begin{aligned}
&\overbrace{u_{C^R,t}\tau_t^R[N(\tau_t^D) - N(\tau_t^R)]}^{\text{Reduce Taxes}} + \overbrace{(1-\lambda)(1-\psi)\beta\mathbb{E}_t[V_B(B_{t+1},N_{t+1},G_{t+1})]B_{t+1}}^{\text{Reduce Debt Burden}} \; > \\
&\underbrace{\kappa u_{C^D,t} N_t^D}_{\text{Output Loss}} + \underbrace{\lambda\beta\mathbb{E}_t[V(B_{t+1},N_{t+1},G_{t+1}) - V^D(B_{t+1},G_{t+1})]}_{\text{Lose Market Access}} + \underbrace{w_b(b_t).}_{\text{Liquidity Catastrophe}}
\end{aligned} \tag{20}
$$

The value of reducing taxes, the first term in Equation 20, depends on the current tax rate $\tau_t^R$ and the potential increase in output $N(\tau_t^D) - N(\tau_t^R)$ from reducing taxes. Defaulting is beneficial if servicing the current debt burden requires considerable fiscal consolidation. The value of reducing the future debt burden primarily depends on the debt reduction $1-\psi$ from default. The larger the haircut the more substantial the debt relief.

The cost of reducing output, the third term in Equation 20, depends on the induced labor wedge $\kappa$. Severe recessions steer policymakers from defaulting. The cost of losing market access depends on the expected time without market access $\lambda^{-1}$ and the value of smoothing taxes $[V(B_{t+1},G_{t+1}) - V^D(B_{t+1},G_{t+1})]$. Without market access policymakers cannot smooth taxes with debt. Lengthy market exclusion compounds the losses from distortionary taxes. The cost of generating a liquidity catastrophe, the fifth term in Equation 20, depends on the marginal value of liquidity $w_b(b_t)$. Substantial demand for safe assets and liquidity amplify the default induced liquidity catastrophe.

With full commitment the debt limit faced by policymakers is the natural debt limit – the highest debt level which can be paid back with certainty. This natural debt limit depends on the government expenditure process and the discount factor. Without commitment the debt limit is endogenous debt

limit – the highest level of debt before policymakers will default. This depends on the expenditure shock process as well as the benefits and costs of default.

Default is more likely when debt is elevated. Formally, for any government expenditure level $G$ there exists a debt level $B^{Endog.}(G)$ such that for all debt above this level, $B > B^{Endog.}(G)$, policymakers will default. Moreover, the endogenous debt limit is lower when government expenditure is higher. Specifically, for any government expenditure levels such that $G' > G$ it follows that $B^{Endog.}(G) > B^{Endog.}(G')$.

### 6.1.2 Interest Rate Manipulation

Policymakers manipulate the interest rate through the default premium, risk premium, and liquidity premium. Let $R_t^{Df} = \beta^{-1} \frac{u_{C,t}}{\mathbb{E}_t[u_{C,t+1}+w_{b,t+1}]}$ is the gross defaultless interest rate, $R_t^{Rf} = \beta^{-1} \frac{1}{\mathbb{E}_t[1+w_{b,t+1}]}$ be the gross riskless interest rate, and $R^f = \beta^{-1}$ be the gross risk-free rate of a risk neutral investor. The spread between the gross equilibrium interest rate $R_t$ and the gross risk-free rate of a risk neutral household $R^f$ equals $\frac{R_t}{R^f}$ and can be written as $(\frac{R_t}{R_t^{Df}}) \cdot (\frac{R_t^{Df}}{R_t^{Rf}}) \cdot (\frac{R_t^{Rf}}{R^f})$. Taking logs of each term I decompose the bond spread $\log\left(\frac{R_t}{R^f}\right) = r_t - r^f$ into the default premium, risk premium, and liquidity premium:

$$\overbrace{r_t - r^f}^{\text{Bond Spread}} = \underbrace{(r_t - r_t^{Df})}_{\text{Default Premium}} + \overbrace{(r_t^{Df} - r_t^{Rf})}^{\text{Risk Premium}} + \underbrace{(r_t^{Rf} - r^f)}_{\text{Liquidity Premium}} \tag{21}$$

.

Policymakers can manipulate the default premium $r_t^{Df} - r_t^{Rf}$ through debt and taxation policy. Even if the government repays this year, $\delta_t = 0$, it could still default next year $\delta_{t+1} = 1$. Keeping tax rates and debt levels low reduces the incentive to default. As the probability of default increases households must be compensated with a default risk premium. To avoid defaulting policymakers can shift tax burden from high expenditure states to low expenditure states. Suppose the policymaker announced a taxation plan with high taxes in the high state and low taxes in the low state. Ex-post the policymaker will default in the high expenditure state to avoid these high taxes. By shifting the tax burden from high to low low states policymakers remove this ex-post incentive to default.

Policymakers manipulate the risk premium $r_t^{Df} - r_t^{Rf}$ through the announced taxation plan $\tau_{t+1}(G_{t+1}$. Raising planned taxes lowers the risk premium today. Through the market clearing condition taxes pin down output and ultimately consumption. The state-contingent taxation plan therefore pins down the expected marginal utility of consumption $\mathbb{E}_t[u_{C,t+1}]$. A rise in the expected marginal utility of consumption reduces the risk premium. Policymakers ability to manage the risk premium depends on households' risk aversion. Risk averse households will not pay a risk premium. Policymakers can manipulate the risk premium to keep interest rates low and the bond spread negative.

Policymakers manipulate the liquidity premium $r_t^{Rf} - r^r$ through debt policy. Unlike the default premium the liquidity premium is negative. Households must compensate the government for providing them with liquidity. If liquidity demand is completely satiated $w_{b,t} = 0$ this premium will shrink to zero. As the debt level rises the default premium rises and the liquidity premium shrinks – both lead to higher interest rates.

## 6.2 Characterizing Optimal Default Policy

### 6.2.1 Calibration

Three parameters, $\{\kappa, \psi, \lambda\} \in [0,1]^3$, dictate the costs and benefits of default. I set the recession size $\kappa = .15$ to match the decline in firm value estimated in Hébert and Schreger (2017) and the output drop in Arellano (2008). I set the market exclusion probability $\lambda = .75$ so average years in financial autarky $(1-\lambda)^{-1} = 4$ aligns with the historical average since 1975 (Uribe and Schmitt-Grohé (2017) and Gelos et al. (2011)). I set the post-default debt burden $\psi = .6$ to match the historical average haircut of 40% (Meyer et al. (2022) and von Luckner et al. (2024)). To illustrate the impact of these parameters on optimal debt policy I consider alternative calibrations in which I eliminate some or all of the default costs. For instance, setting $\kappa$ to zero removes the output loss cost while setting $\psi$ to zero raises the value of debt reduction.

### 6.2.2 Endogenous Debt Limit

| Calibration | | No Assets | | Assets | |
|---|---|---|---|---|---|
| | | No Liquidity | Liquidity | No Liquidity | Liquidity |
| Baseline Default | | 397.87 | 417.12 | 791.06 | 999.73 |
| Costly | | 1219.67 | 3330.85 | 5823.83 | 3528.28 |
| Costless | | 0.00 | 0.00 | 0.00 | 53.77 |
| *Recession Length* | | | | | |
| Short | $\lambda = .5$ | 241.33 | 259.76 | 490.71 | 891.60 |
| Long | $\lambda = .875$ | 700.78 | 564.20 | 1368.11 | 1343.17 |
| *Recession Size* | | | | | |
| Small | $\kappa = 0$ | 0.00 | 0.00 | 0.00 | 59.02 |
| Large | $\kappa = .3$ | 1093.94 | 699.67 | 2577.31 | 1286.54 |
| *Haircut* | | | | | |
| Forgive | $\psi = .3$ | 372.74 | 327.28 | 588.35 | 887.97 |
| Repay | $\psi = .9$ | 797.72 | 575.99 | 1359.83 | 1359.40 |

Table 6: **Endogenous debt ratio limit.** This table presents the maximum debt ratio the government can achieve before optimally defaulting. The rows represent different calibrations of the default parameters $\{\lambda, \kappa, \psi\}$. The baseline default calibration is $(.75, .15, .6)$. The costly default calibration is $(.9, .35, 1)$. The costless default calibration is $(0,0,0)$. Unless stated otherwise, the parameter values match the baseline calibration. Expenditure is set to $G = .14$ and labor taxes are set to $\tau = .496$ for each model.

Table 6 presents the maximal debt ratio policymakers can reach before defaulting. Policymakers default decision depends on the tax rate and expenditure level. I set expenditure to $G = .14$ and labor taxes to $\tau = .496$ to facilitate comparison across models. Each column represents a different model. The right and left set of columns present the endogenous debt limits for models in which the government can and cannot save. Availability of savings significantly raises debt limits. The value of market access, the last term in equation 20, increases with the ability to save. Accessing financial market allows policymakers to build up buffer-stock and precautionary savings. If policymakers are unable to save default is less costly.

Endogenous debt limits can exceed the natural debt limit. Natural debt limits cover the worst possible scenario: a continual crisis and elevated debt position covered by labor taxes. While this situation could happen, it's unlikely. Even if policymakers exceeded the natural debt limit they would most likely exit the crisis period and be able to pay down the excess debt. Endogenous debt limits emerge from the policymakers desire to pay the debt rather than their ability to pay the debt in an extreme scenario. The endogenous debt limit does not converge to the natural debt limit.

Liquidity demand generally raises this endogenous debt limit. At the baseline calibration, regardless of savings ability, debt limits rise with liquidity demand. In a standard model without any cost of default, the costless model in table 6, governments cannot sustain debt. Sustaining debt with only reputation costs, the small recession model in table 6, is impossible. Sovereign debt is sustainable if default triggers a liquidity catastrophe. This result extends the classic Bulow and Rogoff (1989) finding that reputation costs alone are insufficient to maintain debt. When the length and size of recessions are particularly large maintaining heightened debt levels in economies without liquidity demand is possible.

Each row of table 6 presents different calibrations of the default costs. The recession length, recession size, haircut, and liquidity crisis each affect the debt limit. Increasing the cost of default elevates the debt limit. If defaults trigger lengthy recessions policymakers will only default at elevated debt levels. The prospect of triggering a large recession keeps policymakers from defaulting even at extremely high debt levels. Across models debt limits are particularly sensitive to this cost. Policymakers sustain higher debt levels with modest haircuts. If nearly all the debt must be repaid upon market reentry the debt reduction benefits become minor. Default reduces market liquidity. Reducing market liquidity is detrimental enough to support elevated debt levels.

### 6.2.3 Optimal Target

Figure 14 plots the optimal path of the debt ratio during peacetime. Peacetime is represented by a sequence of low expenditure shocks. Absent liquidity demand debt follows a path toward zero. Whereas with liquidity demand the ideal debt target is positive. The savings motive of the policymaker pushes debt toward zero while the satiating motive pulls debt toward the satiation point. Even for policymakers worried about the prospect of war or default, positive debt levels are optimal if markets demand liquidity.

The prospect of defaulting has little impact on the optimal debt target. The optimum debt targets with and without liquidity demand are nearly the same. The availability of default slightly raises the optimal debt target in an economy with liquidity demand. Defaulting on excessive debt burdens is

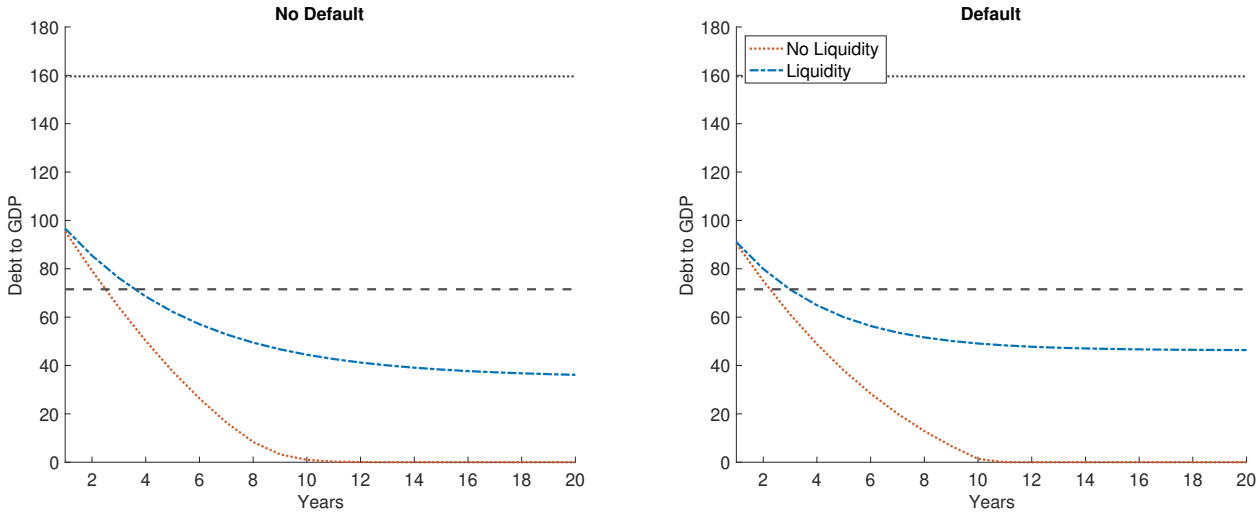



Figure 14: **Optimal policy target with and without default.** This figure plots the optimal path of debt in economies without assets after a seres of low expenditure shocks. The left and right panels consider the cases when the government cannot and can default. Default costs calibrated to the baseline. Asset accumulation disallowed in all models. Each panel plots the optimal debt both for economies with and without liquidity demand.

preferable to exorbitant fiscal consolidation. Defaulting is form of state-contingent debt policy: an escape hatch from enormous debt burdens. Extreme debt levels are less worrisome if policymakers can default.

### 6.2.4 Optimal Policy

Table 7 presents statistics for debt, taxes, and interest rates for models with and without liquidity demand and default. Each model is calibrated to the baseline costs of default.

Regardless of households demand for liquidity policymakers rarely default. Absent liquidity demand, policymakers default 2% of the time; with liquidity demand, policymakers default .7% of the time. Default is less frequent than in other quantitative default models, because default is costlier and policymakers can manipulate interest rates. Taxation distortions and default costs are severe compared to the closed economy model of Pouzo and Presno (2022) or open economy model of Arellano (2008). The shocks in this model are almost three times larger than those models[13]. During financial autarky these sizable government expenditure shocks produce arduous taxation distortions. Output losses are exacting and extended. Small haircuts offer minor debt relief. Repayment is more attractive in this model than other standard models. Additionally, the ability to manipulate interest rates helps policymakers repay loans. As debt approaches the endogenous limit, policymakers can reduce interest rates and curb debt growth.

The option to default reduces the mean and median debt burden. Without liquidity demand, reducing the debt by half avoids default. A minor reduction in debt burden avoids default when

[13]The standard deviation of shocks is .0346 in Pouzo and Presno (2022) and .0945 in my model.

| Statistic | | No Liquidity | | Liquidity | |
|---|---|---|---|---|---|
| | | No Default | Default | No Default | Default |
| *Debt* | | | | | |
| | Probability of Default (%) | 0.00 | 2.10 | 0.00 | 0.70 |
| | Mean Debt Burden | 126.10 | 65.27 | 130.72 | 119.48 |
| | Std. Debt Burden | 157.51 | 84.21 | 65.84 | 55.78 |
| | Median Debt Burden | 31.94 | 25.81 | 108.06 | 102.29 |
| | MAD Debt burden | 135.32 | 66.52 | 52.05 | 42.79 |
| *Labor Taxes* | | | | | |
| | Mean Labor Taxes | 30.26 | 27.57 | 30.55 | 28.97 |
| | Std. Labor Taxes | 11.75 | 6.86 | 9.41 | 8.52 |
| | Corr. with Debt | 0.88 | 0.83 | 0.93 | 0.91 |
| | Corr, with Interest Rate | 0.30 | 0.36 | 0.36 | 0.31 |
| *Interest Rate* | | | | | |
| | Mean Interest Rate | 4.36 | 4.91 | 4.12 | 4.32 |
| | Std. Interest Rate | 5.57 | 7.52 | 4.73 | 7.27 |
| | Corr. with Debt | 0.06 | 0.21 | 0.17 | 0.19 |
| *Bond Spread* | | | | | |
| | Mean Bond Spread | -0.77 | -0.22 | -1.01 | -0.81 |
| | Mean Default Premium | 0.00 | 0.53 | 0.00 | 0.22 |
| | Mean Risk Premium | -0.77 | -0.76 | -0.56 | -0.55 |
| | Mean Liquidity Premium | 0.00 | 0.00 | -0.45 | -0.49 |

Table 7: **Behavior of debt, taxes, and interest rates.** This table presents relevant statistics for debt, taxes and interest rates in a variety of models. I simulate 1000 years of government expenditure shocks in order to measure these statistics. Default costs calibrated to the baseline. Asset accumulation disallowed in all models.

households demand liquidity. Diminishing the debt leads policymakers in both economies to lower labor taxes. In each economy, debt and taxes are highly correlated because policymakers raise both during crises. Default leads interest rates to be more volatile and more correlated with debt. Default amplifies the impact of debt expansions on interest rates. Elevated debt levels satiate liquidity demand without substantially increasing the probability of default.

Despite debt reductions default premia raise the interest rate and bond spread. Even if the government rarely defaults households must be compensated through higher interest rates. Policymakers offset the default premium through the risk premium. By promising to raise taxes during wars policymakers reduce the risk premium and lower interest rates. Policymakers manipulate interest rates so that on average the bond spread is small and negative. The liquidity premium further reduces interest rates and bond spreads.

### 6.2.5 Optimal Policy Near Default

Figure 15 plots the optimal path of debt taxes and interest rates during a long war. Throughout this war policymakers face continually large expenditure shocks. Prior to default liquidity demand

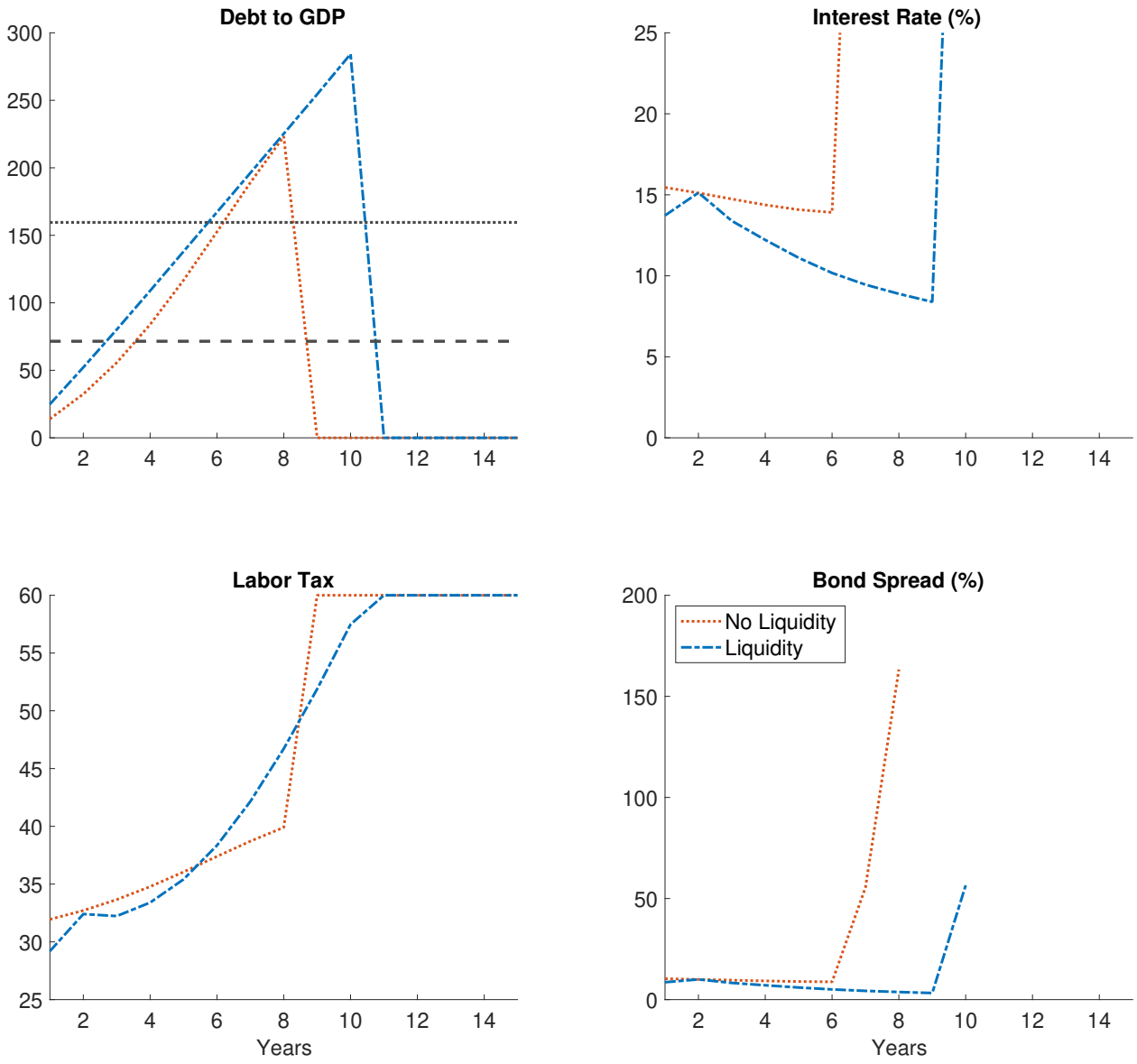



Figure 15: **Optimal policy near default.** This figure plots the optimal path of debt, taxes, and interest rates during a sequence of large expenditure shocks. The debt ratio begins at zero.

leads to lower labor taxes, lower interest rates, and higher debt levels. Absent liquidity demand the government defaults after an 8 year war, when the debt ratio reaches 225%. When households demand liquidity the government defaults after an 11 year war when the debt ratio reaches nearly 300%. The ability to suppress interest rates and the possibility of a liquidity crisis keeps policymakers from defaulting. Policymakers suppress interest rates during the initial debt build up and channel the savings toward reducing labor taxes. After interest rate suppression has been exhausted the government can still maintain debt. The potential cost of a liquidity crisis sustains debt levels past the satiation point. The government is unwilling to sap the market of liquidity unless the situation is quite dire.

# 7 Conclusion

In this paper, I argue that the optimal U.S. public debt level is close to the current level and higher than in standard models. To make this argument, I solve for the optimal Ramsey policy in an incomplete markets model featuring liquidity demand and surplus risk. I find that the optimal debt ratio target is 40-70%. Additionally, in extensions of the baseline model I demonstrate that high debt levels are optimal for policymakers facing liquidity and default risk. Finally, in a complete markets model I show that tax smoothing is dampened in the presence of liquidity demand.

The optimal debt levels in standard incomplete market models do not match the actual public debt levels or the convenience yield in the United States. By calibrating my model to the liquidity demand implied by the low interest rate on Treasury bonds, I find markedly higher optimal debt levels than other incomplete markets models. In contrast to recent papers that similarly match the low interest rates on public debt, I find the optimal debt target is below current levels.

The stark results in this paper stem from the public's demand for U.S. Treasuries. The safety and liquidity of U.S. Treasuries makes them a more attractive savings vehicle than any other private bonds. Given this attractiveness, U.S. policymakers have two options: deprive the market of safe-assets to tax liquidity or satiate the markets desire for safe-assets by taxing labor. For various parameter values and shock processes this paper recommends a combination of both policies.

By focusing on the impact of liquidity demand on optimal debt levels, this paper sets aside important channels. Policymakers should take seriously the possibility of debt cliffs and self-fulfilling debt crises. Even if the U.S. can pay back its debt, bond vigilantes could force a fiscal consolidation if they get nervous. Policymakers should also consider who is buying the debt. If liquidity demand is mainly coming from emerging markets, policymakers should keep the debt closer to the peak of the debt Laffer curve, and allow international bond holders to pay the liquidity tax. More generally, policymakers in emerging economies, with less developed financial markets, should take caution. Liquidity demand is likely much weaker, and the possibility of default is likely much higher.

# Appendices

## A Equilibrium Definition

Before describing optimal policy, I define a feasible allocation, feasible government policy, competitive equilibrium, and the Ramsey problem. These definitions apply in the main text and appendices.

**Definition A.1** (Feasible Allocation)**.** Given an initial debt level $B_0$ and the stochastic government expenditure process $G_t(s^t)$, a *feasible allocation* is a stochastic process $f_t(s^t) = \{C_t(s^t), N_t(s^t)\}$ for consumption and output which satisfies market clearing (equation 7) and whose time $t$ elements are measurable with respect to the initial debt level $B_0$ and the history of government expenditure shocks $G_t(s^t)$.

**Definition A.2** (Competitive Equilibrium)**.** Given an initial debt level $B_0$ and the stochastic government expenditure process $G_t(s^t)$, a *competitive equilibrium* is a feasible allocation, a feasible government policy, and a stochastic real interest rate process $R_t(s^t)$ which satisfies the household's labor-leisure decision (equation 4), the household's liquidity-adjusted Euler equation (5) and the government's intertemporal budget constraint (equation 8).

**Definition A.3** (Feasible Government Policy)**.** Let $\mathbb{P}_t$ be the space of feasible government policies. A *government policy* $p_t(s^t) = \{\tau_t(s^t), T_t(s^t), B_t(s^t)\} \in \mathbb{P}_t$ is a stochastic process for labor taxation $\tau_t(s^t)$, transfers $T_t(s^t)$, the real debt level $B_t(s^t)$ whose time $t$ elements are measurable with respect to the initial debt level $B_0$ and the history of government expenditure shocks $G_t(s^t)$. A *feasible government policy* is a policy $p_t(s^t) \in \mathbb{P}_t(s^t)$ which respects the labor Laffer curve (equation **??**), the restriction on transfers $T_t(s^t) \in \mathbb{R}, \forall s^t$, the natural debt limit (equation **??**) and the natural asset limit $B_t(s^t) \geq 0$.

**Definition A.4** (Ramsey Problem)**.** The *Ramsey problem* is to maximize expected household utility (equation 2) over all competitive equilibria. I define the *continuation Ramsey problem* to be the Ramsey problem faced by the policymaker at time $t \geq 1$ after state $s_t$ has been realized. I define the *initial Ramsey problem* to be the Ramsey problem faced by the policymaker at time $t = 0$.

## B Optimal Taxation with Contingent Debt

This section outlines the optimal Ramsey problem for the complete markets economy. I describes how to reach the solution using the recursive contracts method of Marcet and Marimon (2019). The methodology closely follows Ljungqvist and Sargent (2018) section 20.2.

### B.1 Primal Method

Rewriting the problem faced by policymaker in primal form (i.e. removing prices) simplifies analysis. To convert the problem to primal form, I rewrite the household budget constraint by substituting out the prices faced by households. By substituting the labor tax $1 - \tau_t$ with the labor-leisure

decision (equation 4) and the real interest rate $R_t$ with the liquidity-adjusted Euler equation (5) the household budget is represented in primal form in equation 22.

$$u_{C,t}B_t = u_{C,t}[C_t - T_t] - v_{N,t}N_t + \beta \sum_{s_{t+1}} \Omega(s_{t+1}|s^t)[u_{C,t+1}B_{t+1} + w_b(b_{t+1})b_{t+1}] \tag{22}$$

Everything in the primal budget (equation 22) is priced by marginal utility in order to price debt and taxation in terms of utility. The left-hand side of primal budget is the value of the debt burden. The first two terms on the right-hand side of the primal budget are the total taxes paid to the government net of transfers and government expenditure, i.e. surpluses. The third term on the right-hand side of the primal budget is the expected value of government debt net of the expected liquidity tax $w_b(b_{t+1})b_{t+1}$.

Conditional on government expenditure $G_t$, the labor tax $\tau_t$ is isomorphic to the output level $N_t$. Therefore, for the policymaker selecting the optimal labor tax $\tau_t$ amounts to selecting the optimal output level $N_t$ for a given expenditure level. Put differently, labor tax is a function of the output and expenditure $\tau_t = \tau(N_t, G_t)$.

Selecting the optimal state-contingent debt level $B_{t+1}(s_{t+1})$ is complicated by the future budget constraint. State-contingent debt levels chosen today will be debt obligations tomorrow. The welfare impact of these debt obligations crucially depends on the relative marginal utility of consumption today $u_{C,t}$ compared to tomorrow $u_{C,t+1}$. These marginal utilities price the relative cost taxation, today versus tomorrow, in terms of utility. Future debt also provides liquidity services, priced at the marginal value of liquidity $w_b(b_t, s_t)$. When liquidity is satiated, the marginal value of liquidity is zero, $w_b(b_t, s_t) = 0$ and the value of public debt exclusively depends on the marginal cost of taxation $u_{C,t+1}B_{t+1}$. More generally, the total value of public debt including the value of its liquidity services, in terms of utility is $u_{C,t+1}B_{t+1} + w_b(b_{t+1}, s_{t+1})b_{t+1}$.

Let $\mathscr{B}_t = u_{C,t}B_t + w_b(b_t)b_t$, $\mathscr{T}_t = u_{C,t}[\tau(N_t, G_t)N_t]$, $\mathscr{Q}_t = w_b(b_t, s_t)b_t$, $\mathscr{G}_t = u_{C,t}G_t$ and $\mathscr{R} = \frac{1}{\beta}$ be the marginal utility adjusted debt, labor tax revenues, liquidity tax revenue, government expenditure, and interest rate. The primal budget (equation 22) can be rewritten as,

$$\mathscr{B}_t + \mathscr{G}_t \leq \mathscr{T}_t + \mathscr{Q}_t + \frac{1}{\mathscr{R}} \sum_{s_{t+1}} \Omega(s_{t+1}|s^t)\mathscr{B}_{t+1}. \tag{23}$$

Where the inequality emerges from the availability of lump-sum transfers. This version of the budget equation greatly simplifies analysis as it allows the budget to be written in terms of one state-variable, the value of the future debt $\mathscr{B}_{t+1}$, rather than two, the future debt level $B_{t+1}$ and future promised consumption $C_{t+1}$.

## B.2 Continuation Ramsey Problem

Throughout this section, and the proceeding sections, I describe the Ramsey problem faced by the policymaker recursively. The policymaker, aiming to maximize expected household utility (equation 2) at time $t \geq 1$ solves the following Bellman equation,

$$
\begin{aligned}
V(\mathscr{B},G) = \max_{\{B,C,N,\mathscr{B}_s\}} & \; u(C) - v(N) + w(b,s) + \beta \sum_{s\in S} \Omega(G_s|G) V(\mathscr{B}_s, G_s) \\
\text{s.t } & \; u_C(C)B \leq u_C(C)C - v_N(N)N + \beta \sum_{s\in S} \Omega(s'|s)\mathscr{B}_s \\
& \; C = N - G \\
& \; \mathscr{B} = u_C(C)B + w_b(\frac{B}{N})(\frac{B}{N}) \\
& \; \underline{\mathrm{N}}_s \leq N \leq \bar{N}_s \\
& \; \underline{\mathrm{B}} \leq B \leq \bar{B}
\end{aligned}
\tag{24}
$$

In which utility maximization $V(\mathscr{B},G)$ is subject to the intertemporal budget condition (with corresponding shadow value $\Phi$), market clearing (with corresponding shadow value $\Theta$, government debt commitments (with corresponding shadow value $\Gamma$), and the government policy feasibility constraints on taxes (with corresponding shadow value $\rho_N$), transfers (which leads to the inequality in the budget), and debt issuance (with corresponding shadow value $\rho_B$). The intertemporal budget condition $\Phi$ states that the value of the debt due today $X$ must be paid for by a combination of labor taxation $u_C(C)C - v_N(N)N$, liquidity taxation $w_b(b)b$, and new debt issuance $\beta \sum_{s'\in S} \Omega(G_s|G)\mathscr{B}_s$. The shadow price of commitment $\Gamma$ restricts today's policymaker to honor the real value of government debt $X$ promised by yesterday's planner. This constraint indicates that today's real value of government debt $X$ is the sum of the debt burden $u_C(C)Nb$ and the liquidity tax $w_b(b)b$ which suppresses interest payments on today's debt. The labor feasibility condition $\rho_N$ restricts taxation to be below the peak of the labor Laffer curve (equation **??**). The debt issuance limits are the natural debt limit and the natural asset limit, $Nb > 0$.

Optimal policy consists of decision rules $\{C(\mathscr{B},G), N(\mathscr{B},G), T(\mathscr{B},G), b(\mathscr{B},G), \mathscr{B}_s(\mathscr{B},G;G_s)\}$ for consumption, output, transfers, public debt and the state-contingent value of public debt next period as well as a value function $V(\mathscr{B},G)$. Moreover, these decision rules produce state-dependent shadow values $\{\Phi(\mathscr{B},G), \Theta(\mathscr{B},G), \Gamma(\mathscr{B},G)\}$ for the intertemporal budget condition, market clearing, and government debt commitment conditions. The shadow value of the budget constraint $\Phi(\mathscr{B},G)$ will control labor taxes. while the shadow value of the government commitment condition $\Gamma(\mathscr{B},G)$ will control the liquidity tax. The relative values of each will dictate the relative smoothing of labor taxes versus liquidity. The following sections flesh out how and why.

At time $t = 0$, the policymaker solves the following Bellman Equation,

$$
\begin{aligned}
W(B_0,G_0) = \max_{\{C,N,\mathscr{B}_s\}} & \; u(C) - v(N) + w(\frac{B_0}{N}) + \beta \sum_{s\in S} \Omega(G_s|G) V(\mathscr{B}_s, G_s) & \\
& \; \text{s.t } u_C B_0 \leq u_C C - v_N N + \beta \sum_{s\in S} \Omega(G_s|G)\mathscr{B}_s & (\Phi) \\
& \; C = N - G_0 & (\Theta) \\
& \; \underline{\mathrm{N}}(G_0) \leq N \leq \bar{N}(G_0) & (\rho_N).
\end{aligned}
\tag{25}
$$

I restrict my analysis in the main text to the *continuation* Ramsey problem (equation 24), as the *initial* Ramsey problem (equation 25) is standard (Ljungqvist and Sargent (2018) Section 20.2).

While the solution to the initial Ramsey problem depends on the degree of liquidity-demand, the initial planner does not pick the initial debt level. Therefore the influence of liquidity demand on the optimal debt policy is primarily mediated through the continuation Ramsey problem (equation 24).

## B.3 Labor Tax Smoothing

The interior optimal level of taxation (equation 26) for the Ramsey problem (equation 24),

$$\tau(\mathscr{B},G) = \frac{\Phi(\mathscr{B},G)(\sigma+\eta)}{\Phi(\mathscr{B},G)(1+\eta)-1} + \frac{\Gamma(\mathscr{B},G)-\Phi(\mathscr{B},G)}{1-\Phi(\mathscr{B},G)(1+\eta)}[b-\sigma\frac{N}{N-G}], \tag{26}$$

aims to loosen the budget constraint by raising taxes and provide liquidity through output reduction [14]. The first term on the right-hand side describes how taxes $\tau(\mathscr{B},G)$ should be set for a given level of budget tightness $\Phi(\mathscr{B},G)$. The second term on the right-hand side describes how taxes directly affect liquidity provision. Since liquidity demand is a function of debt-to-output, liquidity provision can be increased by either increasing debt levels or decreasing output. Thus increasing taxes reduces output and raises liquidity provision. This second term would disappear if liquidity demand were proportional to debt levels rather than debt-to-output levels. Numerically, this second term is of second-order importance for setting labor taxes. Therefore, in order to focus on the main source of labor tax fluctuations, I set the shadow value of commitment, $\Gamma(\mathscr{B},G)$, equal to the shadow value of the budget, $\Phi(\mathscr{B},G)$, for the proceeding analysis. So, lets consider

$$\tau(\mathscr{B},G) = \frac{\Phi(\mathscr{B},G)(\sigma+\eta)}{\Phi(\mathscr{B},G)(1+\eta)-1}. \tag{27}$$

The the budget tightness, $\Phi(\mathscr{B},G)$, is equal to shadow value of the intertemporal budget condition. Higher government expenditure $G$ tightens the intertemporal budget, raising the shadow value $\Phi(\mathscr{B},G)$ and thus the incentive to raise taxes. When lump-sum taxes are available, the budget is slack, $\Phi(\mathscr{B},G)=0$, and taxes equal zero each period. When the budget is infinitely tight, $\Phi(\mathscr{B},G)=\infty$, taxes are set to the peak of the Laffer curve $\tau = 1-\frac{1-\sigma}{1+\eta}$.

Perfectly smooth labor taxes requires equalization of the budget tightness across periods, $\Phi(\mathscr{B},G) = \Phi(\mathscr{B}_s,G_s), \forall s \in \mathbb{S}$. Budget tightness $\Phi(\mathscr{B},G)$ is determined by new debt issuance $\mathscr{B}_s$. Formally, the marginal value of relaxing the budget $\Phi(\mathscr{B},G)$ through debt issuance, must be equal to the marginal cost of increased debt tomorrow $V_{\mathscr{B}}(\mathscr{B}_s,G_s)$ for each state. That is, $\Phi(\mathscr{B},G) = V_{\mathscr{B}}(\mathscr{B}_s,G_s)), \forall s \in \mathbb{S}$. Jiang et al. (2022) refer to this as the *p-theory* of taxation, since the marginal cost of debt issuance is the taxation costs tomorrow. Equalization of budget tightness across periods requires equalization of the shadow value of the intertemporal budget across states, $V_{\mathscr{B}}(\mathscr{B},G) = V_{\mathscr{B}}(\mathscr{B}_s,G_s)), \forall s \in \mathbb{S}$.

[14] Labor taxes $\tau_t$ are isomorphic to output $N_t$, therefore setting the optimal tax rate amounts to setting the optimal output level $N_t$. The optimal taxation equation (26) emerges from rearranging terms.

Marginal cost of debt $V_{\mathscr{B}}(\mathscr{B},G)$ is increasing in the level of government expenditure, $G_{s'} > G_s \Rightarrow V_{\mathscr{B}}(\mathscr{B},G_{s'}) > V_{\mathscr{B}}(\mathscr{B},G_s), \forall s \neq s' \in \mathbb{S}$. Therefore, equalization of marginal debt costs $V_{\mathscr{B}}(\mathscr{B},G)$ requires a reduction of the value of the debt $\mathscr{B}_s$ in high government expenditure states $G_s$. In other words, the government partially defaults when hit with a government expenditure shock in order to equalize outlays across periods. Equalization of outlays across periods facilitates labor tax smoothing. Absent liquidity demand, this is optimal.

## B.4 Liquidity Tax Smoothing

The interior solution for the optimal debt level is described by equation 28. The optimal debt level balances the desires to smooth labor taxes, satiate liquidity demand, and tax liquidity. The first-term on the left-hand side is the debt level that satiates liquidity $b^{Liq.Sat.}$. The first term on the right-hand side is the peak of the debt Laffer curve $b^{Laffer}$ which maximizes the liquidity tax. The second term on the right-hand side is the debt level that smoothes labor taxes. Notice that if households did not desire liquidity, $w_b(b) = 0$, then budget tightness is equalized $\Gamma(\mathscr{B},G) = \Phi(\mathscr{B},G)$. In other words $V_{\mathscr{B}}(\mathscr{B},G) = V_{\mathscr{B}}(\mathscr{B}_s,G_s), \forall s$. When this is the case, labor taxes are smooth.

$$[w_b(b)] = \Gamma(\mathscr{B},G)[w_b(b) + w_{bb}(b)b] + (\Gamma(\mathscr{B},G) - \Phi(\mathscr{B},G))[u_C N] \tag{28}$$

With liquidity demand, the government budget commitment constraint $\Gamma(\mathscr{B},G)$ controls the liquidity tax. Let's ignore the tax smoothing incentive for a moment, by setting $\Gamma(\mathscr{B},G) = \Phi(\mathscr{B},G)$, so that the optimal level of the liquidity tax is solely determined liquidity demand. That is, $[w_b(b)] = \Gamma(\mathscr{B},G)[w_b(b) + w_{bb}(b)b]$. When the commitment constraint does not bind, $\Gamma(\mathscr{B},G) = 0$, liquidity is completely satiated and the debt-to-output level is $b^{Liq.Sat.}$. As the constraint tightens, $\Gamma(\mathscr{B},G) > 0$, liquidity is taxed and the debt-to-output ratio falls toward the peak of the debt Laffer curve $b^{Laffer}$. Liquidity smoothing requires equalization of the shadow value of the commitment constraint across periods $\Gamma(\mathscr{B},G) = \Gamma_s(\mathscr{B}_s,G_s), \forall s \in \mathbb{S}$. Liquidity smoothing requires equalization of debt across states $B = B_s, \forall s$.

## B.5 Tradeoff Between Labor and Liquidity Tax Smoothing

Policymakers aim to simultaneously smooth labor and liquidity taxes. This is impossible. To see how this tradeoff manifests, I rearrange the optimal debt equation, and judiciously substitute $V_{\mathscr{B}}(\mathscr{B},G)$ and $V_{\mathscr{B}}(\mathscr{B}_s,G_s)$ for shadow values $\Phi(\mathscr{B},G)$ and $\Gamma(\mathscr{B},G)$, so that

$$[V_{\mathscr{B}}(\mathscr{B},G) - V_{\mathscr{B}}(\mathscr{B}_s,G_s)] = \frac{[w_b(b) - \Gamma(\mathscr{B},G)(w_b(b) + w_{bb}(b)b)]}{u_C N} \tag{29}$$

The term in brackets on the left-hand side is the labor tax smoothing condition, while the term in brackets on the right hand side is the liquidity tax smoothing condition. Labor tax smoothing requires debt devaluations during crises, and liquidity tax smoothing requires debt smoothing across states $B_s = B_{s'}.\forall s \neq s'$. By equation 29, we see that deviation from labor tax smoothing equals the

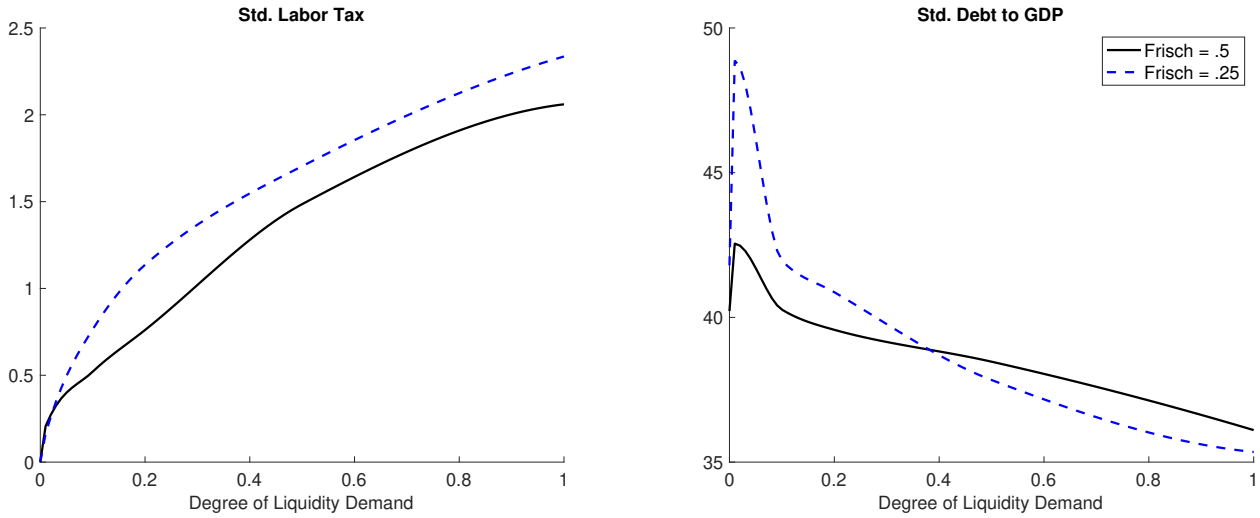



Figure 16: **Volatility of labor taxes and debt ratio.** This figure plots the standard deviation of the optimal labor tax and debt-to-output ratio for different parameter values. This standard deviation is taken over a 500 year sample after a 1000 year burnin period. The left panel plots the optimal labor tax rate, the right panel plots the optimal debt ratio. The x-axis in both panels presents the liquidity demand parameters: $\{x\nu, x\phi\}$ for $x \in [0,1]$. In each panel I plot the standard deviation for different values of the Frisch elasticity $\eta^{-1}$.

liquidity distortion that period. As the labor tax increases, so does the liquidity tax. Policymakers partial tax both labor and liquidity. This fits with the public finance intuition of expanding the base and lowering the rate.

Figure 16 clarifies how the interaction of liquidity demand parameters and the Frisch elasticity impact the policymaker's tradeoff. The left panel plots the standard deviation of labor taxes and the right panel plots the standard deviation of debt ratio for different liquidity demand parameters. The x-axis records the coefficient multiplied by the baseline liquidity demand parameters; at the origin there is no liquidity demand and at unity is the baseline liquidity demand. For a given set of liquidity demand parameters the Frisch elasticity dictates which smoothing motive is more powerful. A large Frisch elasticity amplifies tax fluctuations effects on output fluctuations. This amplification leads the policymaker to prioritize labor tax smoothing over liquidity smoothing.

As the degree of liquidity demand increases, the volatility of labor taxes increases. In a Lucas and Stokey (1983) economy without liquidity demand, labor taxes are constant. For a given degree of liquidity demand, the policymaker increases the volatility of taxes less if the Frisch elasticity is larger. As the degree of liquidity demand increases the volatility of the debt ratio decreases. Liquidity demand raises the volatility of the debt ratio *within* states and reduces the volatility *across states*. For large enough liquidity demand this second force outweighs the first. A larger Frisch elasticity dampens the first force and amplifies the second.

## B.6 Determinacy of Debt

In my model there is an invariant distribution of debt independent of the initial debt level. Even with state-contingent debt and quasilinear utility, there is a unique optimal long run debt level. I illustrate this in figure 17.

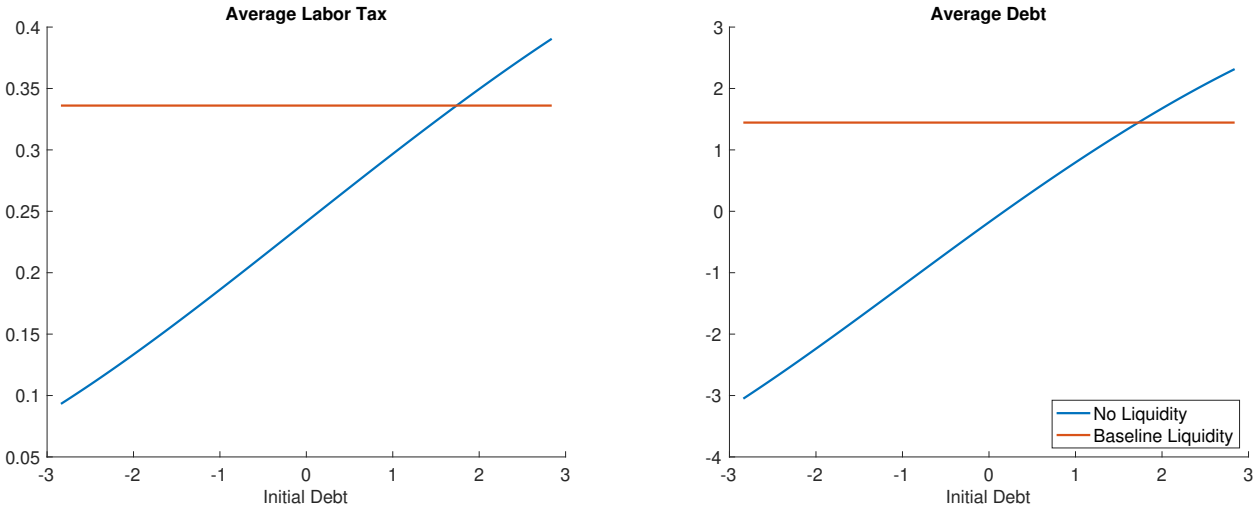



Figure 17: **Determinacy of debt.** This figure plots the initial debt level against the average debt level and tax rate for the complete markets model.

Determinacy of debt in optimal policy plans crucially depends on the state-contingency of debt instruments, concavity of households utility functions, the availability of lump-sum transfers, and the expenditure shock process. First, access to state-contingent debt, as in Lucas and Stokey (1983), leads to an indeterminate optimal debt level. In this case, the policymaker smooths all future labor taxes at a level commensurate with the initial debt level. This can be seen in figure 17. The long-run optimal debt level moves in tandem with the initial level. Second, ruling out state-contingent debt but allowing lump-sum transfers to households with quasilinear preferences, as in Aiyagari et al. (2002), leads to a continuum of invariant distributions of debt. In this case, the policymaker replicates a complete-markets equilibrium by amassing a war chest of assets (i.e. large negative debt). There is a continuum of invariant debt distributions because there is a range of asset levels which can cover all future expenditure shocks. Third, introducing concave consumption utility, as in Bhandari et al. (2017a), leads to a unique invariant distributions of debt, labor taxes, and interest rates. In this case, the policymaker replicates a complete-markets equilibrium by amassing assets and varying the interest-rate paid by households to cover expenditure fluctuations.

# C Optimal Taxation with Noncontingent Debt

This section outlines the optimal Ramsey problem for the incomplete markets economy. I describes how to reach the solution using the recursive contracts method of Marcet and Marimon (2019). The methodology closely follows Ljungqvist and Sargent (2018) section 20.3.

## C.1 Primal Method

Risk-free debt requires that the household and government choose tomorrow's debt level today. Therefore the household budget constraint,

$$C_t + \frac{B_t}{R_t} = (1-\tau_t)N_t + B_{t-1} + T_t,$$

now indexes next periods debt level $B_t$ with time index $t$ to indicate that this debt level is chosen after history $s^t$. After substituting out the labor tax $1-\tau_t$ with the labor leisure decision (equation 4), and the real interest rate with the liquidity-adjusted Euler equation (5), the household budget is written in primal form as

$$u_{C,t}B_{t-1} = u_{C,t}[C_t - T_t] - v_{N,t}N_t + \beta \sum_{s_{t+1}} \Omega(s_{t+1}|s^t)[u_{C,t+1}B_t + w_b(b_t)b_t]. \tag{30}$$

Where debt-to-output tomorrow $b_{t+1} = \frac{B_t}{N_{t+1}}$ depends on the debt issued today and output tomorrow. Just as in the state-contingent debt case (Section 4), selecting the optimal debt level $B_t$ is complicated by the future budget constraint. The debt issued by the government today $B_t$, will impact tomorrows budget. The welfare impacts of the debt issuance today depend on the marginal utility of consumption tomorrow $u_{C,t+1}$ and the marginal value of liquidity tomorrow $w_b(b_{t+1})$. Since these are uncertain, the *expected* value of public debt is $\mathscr{B}_t = \mathbb{E}_t[u_{C,t+1}B_t + w_b(b_t)b_t]$. Let $\mathscr{R}_t = \frac{u_{C,t}B_{t-1}+w_{b,t}b_t}{\mathbb{E}_{t-1}[u_{C,t}B_{t-1}+w_{b,t}b_t]}$ be the marginal utility adjusted realized interest rate. Let $\mathscr{T}_t = [u_{C,t} - v_{N,t}]N_t$ be the marginal utility adjusted labor tax revenue. Let $\mathscr{Q}_t = w_{b,t}b_t$ be the liquidity tax revenue. Let $\mathscr{G}_t = u_{C,t}G_t$ be the marginal utility adjusted government expenditure level. The primal budget (equation 30) can be rewritten as,

$$\mathscr{B}_{t-1}\mathscr{R}_t + \mathscr{G}_t \leq \mathscr{T}_t + \mathscr{Q}_t + \beta\mathscr{B}_t. \tag{31}$$

Where the inequality emerges from the availability of lump-sum transfers. This version of the budget greatly simplifies analysis as it allows the budget to be written in terms of one state-variable, the expected value of the future debt $\mathscr{B}_t$. Writing the budget condition in this way makes clear that the expected value of the future debt $|debt_{t-1}$ after history $s^{t-1}$ affects the budget constraint for all possible histories $s^t = (s^{t-1}, s_t)$. The configuration of the budget allows me to utilize the expectations parameterization method of Marcet and Marimon (2019) when solving for optimal policy.

## C.2 Ramsey Problem

In this section I describe the Ramsey problem faced by the policymaker recursively. The policymaker, aiming to maximize expected household utility (equation 2) at time $t \geq 1$, solves the following Bellman Equation,

$$
\begin{aligned}
V(\mathscr{B},G) = \max_{\{B,C_s,N_s,\mathscr{B}_s\}} & \sum_{s\in S}\Omega(G_s|G)[u(C_s)-v(N_s)+w(\frac{B}{N_s})+\beta V(\mathscr{B}_s,G_s)] \\
\text{s.t } & u_C(C_s)B \leq u_C(C_s)C_s - v_N(N_s)N_s + \beta\mathscr{B}_s && (\Omega(G_s|G)\Phi_s) \\
& C_s = N_s - G_s && (\Omega(G_s|G)\Theta_s) \\
& \mathscr{B} = \sum_{s\in S}\Omega(G_s|G)[u_C(C_s)B + w_b(\frac{B}{N_s})\frac{B}{N_s}] && (\Gamma) \\
& \underline{\mathrm{N}}_s \leq N_s \leq \bar{N}_s && (\Omega(G_s|G)\rho_{N_s}) \\
& \underline{\mathrm{B}} \leq B \leq \bar{B} && (\rho_B \sum_{s\in S}\Omega(G_s|G)).
\end{aligned}
\tag{32}
$$

In which utility maximization $V(\mathscr{B},G)$ is subject to the intertemporal budget conditions (with corresponding shadow values $\Phi_s$), market clearings (with corresponding shadow values $\Theta_s$, government debt commitment (with corresponding shadow value $\Gamma$), and the government policy feasibility constraints on taxes (with corresponding shadow values $\rho_{N_s}$), transfers (with corresponding shadow value $\rho_T$), and debt issuance (with corresponding shadow value $\rho_B$). The policymaker selects the debt level $B$ before the state $s$ is realized, but can condition consumption $C_s$, output $N_s$, transfers $T_s$ and the expected value of the debt $\mathscr{B}_s$ on next period's state.

The intertemporal budget conditions $\Phi_s$ state that the expected value of the debt due today $\mathscr{B}$ must be paid for by a combination of labor taxation $u_C(C_s)C_s - v_N(N_s)N_s$, liquidity taxation $w_b(\frac{B}{N_s},s)\frac{B}{N_s}$, and new expected debt issuance $\beta\mathscr{B}_s$. The shadow price of commitment $\Gamma$ restricts today's policymaker to honor the expected value of government debt $\mathscr{B}$ promised by yesterday's planner. This constraint indicates that today's expected value of government debt $\mathscr{B}$ is the sum of the expected debt burden $\sum_{s\in S}\Omega(G_s|G)[u_C(C_s)N_s b_s]$ and the expected liquidity tax $\sum_{s\in S}\Omega(G_s|G)[w_b(\frac{B}{N_s},s)\frac{B}{N_s}]$ which suppresses interest payments on today's debt by taxing liquidty. The labor feasibility condition $\rho_N$ restricts taxation to be below the peak of the labor Laffer curve (equation **??**). The debt issuance limits are the natural debt limit and the natural asset limit, $Nb > 0$. Government expenditure $G_s$ and liquidity demand $w(b_s,s)$ are indexed by the state $s$ to indicate that expenditure and the degree of liquidity demand are exogenous.

Optimal policy consists of decision rules $\{C_s(\mathscr{B},G),N_s(\mathscr{B},G),T_s(\mathscr{B},G),b(\mathscr{B},G),\mathscr{B}_s(\mathscr{B},G)\}$ for consumption, output, transfers, public debt and the expected value of public debt next period as well as a value function $V(\mathscr{B},G)$. Moreover, these decision rules produce shadow values $\{\Phi_s(\mathscr{B},G),\Theta_s(\mathscr{B},G),\Gamma(\mathscr{B},G)\}$ for the intertemporal budget condition, market clearing, and government debt commitment conditions. As in the previous section, the shadow value of the budget constraints $\Phi_s(\mathscr{B},G)$ will control labor taxes, while the shadow value of the government commitment condition $\Gamma(\mathscr{B},G)$ will control the liquidity tax. The relative values of each will dictate the relative level of labor and liquidity taxes. The following sections flesh out how and why.

At time $t = 0$, the policymaker solves the following Bellman Equation,

$$
\begin{aligned}
W(B_0, G_0) = \max_{\{C,N,\mathscr{B}\}} & \; u(C) - v(N) + w(\frac{B_0}{N}) + \beta V(\mathscr{B}, G_0) \\
\text{s.t} \;\; & u_C B_0 \leq u_C C - v_N N + \beta \mathscr{B} && (\Phi) \\
& C = N - G_0 && (\Theta) \\
& \underline{\mathrm{N}}(G_0) \leq N \leq \bar{N}(G_0) && (\rho_N).
\end{aligned} \tag{33}
$$

As in the previous section, I focus my analysis on the continuation Ramsey problem (equation 32) as the initial Ramsey problem (equation 33) is standard (Ljungqvist and Sargent (2018) Section 20.3).

## C.3 Savings Motive

Conditional on expenditure $G_s$, labor taxes $\tau(s)$ in state $s$ are isomorphic to output $N(s)$, therefore setting the optimal labor tax rate amounts to setting the optimal output level $N(s)$. For ease of notation, I ignore the bounds on the tax rate and focus on the interior solution. The optimal output (equation 34) for the Ramsey problem (equation 32), balances the desire to pay down the debt, pay for government expenditure, keep taxes low, and minimize fluctuations in taxes. The left-hand side of the optimal labor taxation equation (34) is the first-best tax rate: zero. The first term on the right-hand side is the peak of the Laffer curve, the maximum tax revenue the government can raise. The second term on the right-hand side is the incentive to pay down the debt through increased taxation. The third term on the right-hand side is the impact on the liquidity tax through the interest rate from increasing labor taxes. Since the demand for liquidity is in terms of debt-to-output $b_s = \frac{B}{N_s}$, increasing taxes indirectly increases liquidity. By raising taxes, and lowering output $N_s$, the relative debt required to satiate liquidity falls.

$$
\begin{aligned}
u_C(C_s) - v_N(N_s) = & \; \Phi_s[(1-\sigma)u_C(C_s) - (1+\eta)v_N(N_s)] + (\Gamma - \Phi_s)[u_{CC,s}B] \\
& - \frac{B}{N_s^2}[w_b(\frac{B}{N_s}, s) - \Gamma(w_b(\frac{B}{N_s}, s) + w_{bb}(\frac{B}{N_s}, s)\frac{B}{N_s})]
\end{aligned} \tag{34}
$$

Again the impact of labor taxes on liquidity taxes mediated through the last term is second-order. Setting this term to zero and rearranging the equation we see that labor taxes equal

$$
\tau_s = \frac{\Phi_s(\sigma+\eta)}{\Phi_s(1+\eta)-1} + \sigma\frac{(\Gamma - \Phi_s)}{\Phi_s(1+\eta)-1}\frac{B}{C_s}. \tag{35}
$$

With risk-free debt, tax-smoothing is no longer possible. Labor taxes are no longer solely a function of budget tightness. The incentive to pay down the debt also affects labor taxation. Increasing the debt increases labor taxation. Moreover, by building up precautionary and buffer stock savings, policymakers can reduce labor taxes. Clearing with enough assets, $B << 0$, policymakers can set labor taxes to zero. This incentive, which materializes as the second term in equation **??**, leads policymakers to save assets.

## C.4 Debt and Taxes are Random Walks

Government expenditure shocks, rather than being entirely absorbed by fluctuations in the government debt as in Lucas and Stokey (1983), now are partially financed by debt and taxes. Increased budget tightness leads to increased debt issuance and labor taxes. To see this I discuss optimal labor taxes, absent liquidity demand. Suppose first that households don't demand liquidity. Then, by the combining the first-order conditions for debt $B$, next years value of debt issuance $\mathscr{B}_s$, and the envelope theorem for this years debt issuance $\mathscr{B}$, we get that

$$\Gamma = \sum_s \tilde{\Omega}_s \Phi_s.$$

Where $\tilde{\Omega}_s = \frac{\Omega_s u_C(C_s)}{\sum_{\tilde{s}} \Omega_{\tilde{s}} u_C(C_{\tilde{s}})}$ is the value-weighted probability of state $s$. The government budget tightness $\Phi_s$ strictly negative. Thus $\Phi_s < \Phi_{s'}$ implies that the budget is tighter in state $s$ compared to state $s'$. When the government budget is tighter than the value-weighted average budget tightness, $\Phi_s < \sum_s \tilde{\Omega}_s \Phi_s$, due to a government expenditure shock, the policymaker raises labor taxes. The inability to issue state-contingent debt forces the government to depart from tax-smoothing, the second-best policy.

In order to soften the impact of budget tightening on labor taxes, this rise in labor taxes is accompanied by a rise in public debt. By first-order maximization $\Phi_s = V_{\mathscr{B}}(\mathscr{B}_s, G_s)$ and by the envelope theorem $\Gamma = V_{\mathscr{B}}(\mathscr{B}, G)$. Therefore, budget tightening, $\Phi_s < \Gamma$ implies that the marginal value of debt issuance is greater than the marginal value of debt $V_{\mathscr{B}}(\mathscr{B}_s, G_s) < V_{\mathscr{B}}(\mathscr{B}, G)$. Since the marginal value of debt $V_{\mathscr{B}}(\mathscr{B}_s, G_s)$ is decreasing, the government issues new debt, $|debt_s > \mathscr{B}$. Intuitively, the government elects to raise the government debt in order to transfer some of the labor taxes from the state in which the welfare costs are large to a state in which the welfare costs are low.

Absent transfers, $T_s = 0$, this implies that the expected value of the debt $\mathscr{B}$, the debt level $B$, and labor taxes $\tau(s)$ are random walks. To echo the intuition of Barro (1979), the labor tax should equal the expected discounted value of all future tax obligations.

With positive, transfers $T_s \geq 0$, the value of the debt $\mathscr{B}$, the debt level $B$, and labor taxes $\tau(s)$ are random walks with a downward trend. In other words, the government builds up a war-chest of assets and uses it to reduce labor taxes. Positive transfers allow the policymaker to rebate excess revenue back to households. This makes the marginal value of debt $V_{\mathscr{B}}(\mathscr{B}_s, G_s) \leq 0$ non-positive. By the martingale convergence theorem, $V_{\mathscr{B}}(\mathscr{B}_s, G_s)$ converges to zero almost surely (Aiyagari et al. (2002)). The random walk nature of debt combined with the incentive to save causes the debt to slowly converge downward.

## C.5 Satiating Motive

Policymakers have an incentive to satiate liquidity demand. Issuing debt provides household with liquid assets. The optimal debt level $B$ for the Ramsey problem (equation 32) is given by,

$$\sum_s \hat{\Omega}_s w_{b,s} = \Gamma \sum_s \hat{\Omega}_s (w_{bb,s} b_s + w_{b,s}) + (\sum_s \Omega_s N_s^{-1})^{-1} \sum_s \Omega_s (\Gamma - \Phi_s) u_{C,s}. \tag{36}$$

Where $\hat{\Omega}_s = \frac{\Omega_s N_s^{-1}}{\sum_s \Omega_s N_s^{-1}}$ is the inverse-output weighted probability of state $s$. The first-term on the left-hand side is the debt level that satiates liquidity $b^{Liq.Sat.}$.The first term on the right-hand side is the peak of the debt Laffer curve $b^{Laffer}$ which maximizes the liquidity tax. The second term on the right-hand side is the debt level that smoothes labor taxes, in the random walk sense. Absent liquidity demand, debt acts as a shock absorber and is a random walk. In order to focus on the impact of liquidity demand on optimal debt issuance lets set the last term on the right in equation 36 to zero. Then, $\sum_s \hat{\Omega}_s w_{b,s} = \Gamma \sum_s \hat{\Omega}_s (w_{bb,s} b_s + w_{b,s})$. This is a tradeoff region of the debt Laffer curve. Policymakers want to set debt levels between the debt satiating point (the term on the left) and the peak of the debt Laffer curve (the term on the right). Absent aggregate shocks, policymakers would always keep debt in this tradeoff region.

## C.6 Tradeoff Between Saving and Satiating

Policymakers aim to simultaneously lower labor taxes through savings and satiating liquidity demand by dissaving. Policymakers can't do both. By rearranging the optimal debt equation and substituting out the shadow values we see that

$$V_{\mathscr{B}}(\mathscr{B}_s, G_s) - \sum_s \tilde{\Omega}_s V_{\mathscr{B}}(\mathscr{B}_s, G_s) = \gamma [\sum_s \hat{\Omega}_s w_{b,s} - \Gamma \sum_s \hat{\Omega}_s (w_{bb,s} b_s + w_{b,s})]. \tag{37}$$

Where $\gamma = \frac{\sum_s \Omega_s N_s^{-1}}{\sum_s \Omega_s u_{C,s}}$. The left hand side of equation 37 is the savings motive and the right hand side is the satiating motive. Left-hand side is also the random-walk term that causes debt to increase during crises. Even with liquidity demand this term remains and policymakers partially debt-finance crises. But the satiating motive keeps policymakers from accumulating as many assets. As liquidity demand declines, i.e. $w(b_s) \to 0$, this savings-satiating tradeoff disappears and policymakers accumulate assets. Similarly, the disappearance of aggregate risk, i.e. $G_s \to G \; \forall s$, removes the incentive to save and policymakers stay in the debt laffer Curve tradeoff region. The relative power of each force is a quantitative question.

Figure 18 illustrates the average labor tax and debt-to-output level across different parameterizations of the model. Holding liquidity demand constant, a larger intertemporal elasticity of substitution reduces the average labor tax and debt level. At the baseline level of liquidity demand, the average debt-to-output level is approximately 150 % for an IES of 1 and 100% for an IES of 1.4. An increase in the IES reduces the average labor tax and debt-to-output level for any degree of liquidity demand. At the half the baseline level of liquidity demand, the average debt-to-output level is approximately 120 % for an IES of 1 and 70% for an IES of 1.4.

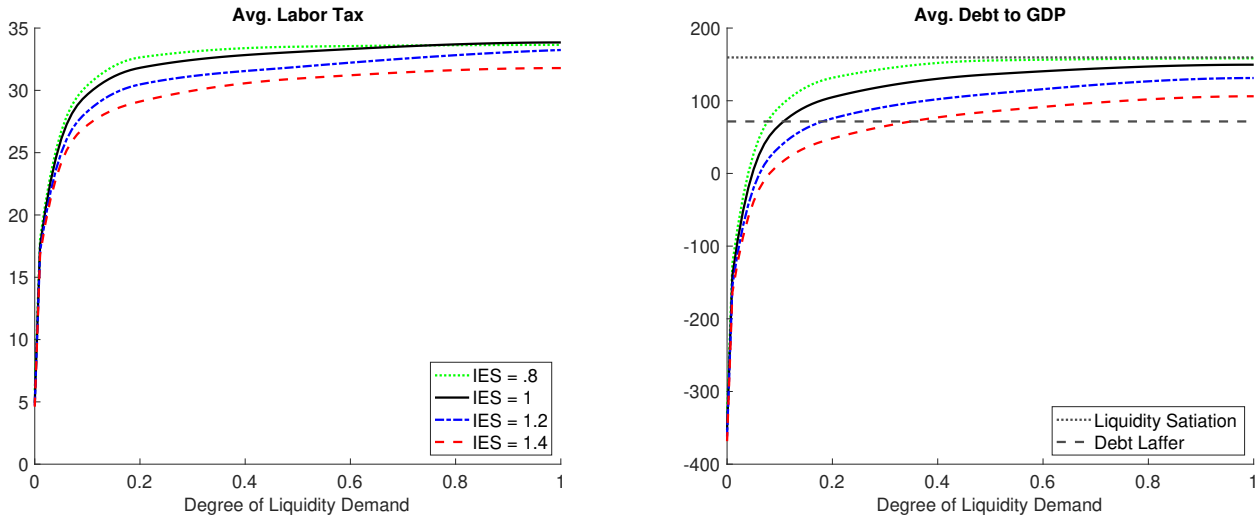



Figure 18: **Level of labor taxes and debt-to-output.** This figure plots the average of the optimal labor tax and debt-to-output ratio for different parameter values. This average is taken over a 500 year sample after a 1000 year burnin period. The left panel plots the optimal labor tax rate, the right panel plots the optimal debt-to-output ratio. The x-axis in both panels presents the liquidity demand parameters: $\{x\nu, x\phi\}$ for $x \in [0,1]$. In each panel I plot the average for different values of the IES $\sigma^{-1}$.

# D Stochastic Liquidity Demand Model

The stochastic liquidity demand model is nearly identical to the noncontingent debt model. The only difference being the source of aggregate risk. In this model policymakers aim to insure against *liquidity risk* rather than *surplus* risk. History $s^t$ describes the history of liquidity demand shocks $\{\nu_s\}_{s=0}^t$. Transition probabilities are functions of liquidity demand $\Omega_{t+1}(s^{t+1}|s^t) = \Omega(\nu_{t+1}|\nu_t)$. The Ramsey problem is otherwise identical to equation 32.

## D.1 Continuation Ramsey Problem

$$
\begin{aligned}
V(\mathscr{B},\nu) = \max_{\{B,C_s,N_s,T_s,X_s\}} \sum_{s\in S} \Omega(\nu_s|\nu)[u(C_s) - v(N_s) + w(\frac{B}{N_s},\nu_s) + \beta V(\mathscr{B}_s,\nu_s)] & \\
\text{s.t } u_C(C_s)B = u_C(C_s)[C_s - T_s] - v_N(N_s)N_s + \beta\mathscr{B}_s & \quad (\Omega(\nu_s|\nu)\Phi_s) \\
C_s = N_s - G_s & \quad (\Omega(\nu_s|\nu)\Theta_s) \\
\mathscr{B} = \sum_{s\in S} \Omega(\nu_s|\nu)[u_C(C_s)B + w_b(\frac{B}{N_s},\nu_s)\frac{B}{N_s}] & \quad (\Gamma) \\
\underline{\mathrm{N}}_s \le N_s \le \bar{N}_s & \quad (\Omega(\nu_s|\nu)\rho_{N_s}) \\
\underline{\mathrm{B}} \le B \le \bar{B} & \quad (\rho_B \sum_{s\in S} \Omega(\nu_s|\nu))
\end{aligned}
\tag{38}
$$

At time $t = 0$, the policymaker solves the following Bellman Equation,

$$
\begin{aligned}
W(B_0, \nu_0) = \max_{\{C,N,\mathscr{B}\}} & \; u(C) - v(N) + w(\frac{B_0}{N}, \nu_0) + \beta V(\mathscr{B}, \nu_0) \\
\text{s.t} \;\; & u_C B_0 \leq u_C C - \nu_N N + \beta \mathscr{B} && (\Phi) \\
& C = N - G_0 && (\Theta) \\
& \underline{\mathrm{N}}(G_0) \leq N \leq \bar{N}(G_0) && (\rho_N).
\end{aligned} \tag{39}
$$

As in the previous section, I focus my analysis on the continuation Ramsey problem (equation 38) as the initial Ramsey problem (equation 39) is standard (Ljungqvist and Sargent (2018) Section 20.3).

# E Strategic Default Model

## E.1 An Economy with Strategic Default

This economy builds on the model presented in section 2. Time is discrete and the government must finance a stochastic stream of government expenditure. Firms and household have identical preferences and the government issues one-period noncontingent bonds. Unlike the economy in section 2, policymakers can strategically default on these bonds. There are costs and benefits to defaulting that the government considers each period. If the costs are large enough to rule out default, optimal policy will resemble the Ramsey policy in 4.

### E.1.1 Government

The government funds an exogenous stream of government expenditure by levying distortionary labor taxes and issuing one-period liquid bonds to domestic households. Policymakers do not have full commitment and can ex-post default on previously issued bonds. After observing the government expenditure level $G_t$ in year $t$, but before issuing new liquid bonds $B_t$, the government decides whether to repay its previously issued debt $B_{t-1}$ or default. Default triggers a recessionary period during which the government is barred from issuing new debt. While in financial autarky the government must use labor taxation to pay for government expenditure. Defaulting reduces the debt burden and current taxes but removes market access.

Let $\delta_t \in \{0,1\}$ be the government's default decision in year $t$. The default decision $\delta_t$ takes a value of 1 if the government defaults and zero otherwise. Repaying policymakers face the usual intertemporal budget constraint: $B_{t-1} + G_t + T_t = \tau_t N_t + \frac{B_t}{R_t}$. Defaulting policymakers face the intratemporal budget constraint: $G_t + T_t = \tau_t \kappa N_t$. The parameter $\kappa \in [0,1]$ captures the output loss from the default induced recession.

Let $\mu_t$ be a variable that takes a value of 1 when policymakers have financial market access and a value 0 while in financial autarky. Policymakers retain market access through repayment. Policymakers lose market access through default. Defaulting triggers a recessions and sends the govern-

ment into financial autarky. With probability $\lambda \in [0,1]$ the recession continues next year and the government remains in financial autarky. The law of motion for market access is

$$\mu_t = \mu_{t-1}(1-\delta_t) + (1-\mu_{t-1})\zeta_t. \tag{40}$$

Where $\zeta_t$ is a Bernoulli distribution with probability $1-\lambda$. On average these recessions last for $(1-\lambda)^{-1}$ years. If the government regains market access it takes a fixed haircut $(1-\psi) \in [0,1]$ on its previous debt burden $B_{t-1}$. Upon market reentry the government decides whether to repay this reduced debt burden $\psi B_{t-1}$ or default again[15].

When policymakers issue new debt $B_t$ they simultaneously announce state-contingent taxes for next year $\tau_{t+1}(G_{t+1})$. Repaying governments must also honor last year's taxation plan. Defaulting governments can deviate from the previous taxation plan. Policymakers in financial autarky still set out a state-contingent tax plan to be implemented upon market reentry. Announcing state-contingent labor taxes allows policymakers to manipulate current interest rates.

### E.1.2 Household

The household consumes goods $C_t$, supplies labor $N_t$, and buys one period liquid bonds $B_t$. The household taxes labor taxation $\tau_t$, interest rates on safe assets $R_t$, transfers $T_t$, output $Y_t$ and the government default decision $\delta_t$ as given. Since policymakers can default the household budget constraint is:

$$C_t + \frac{B_t}{R_t} = (1-\tau_t)(1-\kappa(1-\mu_t))N_t + (1-\delta_t)B_{t-1} + T_t. \tag{41}$$

When the government repays, i.e. $\delta_t = 0$, the household faces the same budget as in the baseline model outlined in section 2. When the government defaults, i.e. $\delta = 1$, the household loses access to previously saved assets $B_{t-1}$ and contends with a labor wedge $(1-\kappa)$ induced by the recession. The $\kappa N_t$ lost in recessions is a pure deadweight loss. Output market clearing implies that $(1-\kappa\mu_t)N_t = C_t + G_t$.

Given budget constraint 41, the household maximizes expected lifetime utility,

$$\max_{\{C_t,N_t,B_t\}_t} \mathbb{E}_0 \sum_t \beta^t \sum_{s^t} \Omega_t [u(C_t) - v(N_t) + w((1-\mu_t)b_t)]. \tag{42}$$

Where $b_t = \frac{B_{t-1}}{Y_t}$ is the debt-to-GDP ratio. While in financial autarky, i.e. $\mu_t = 0$, households lose access to liquidity.

Optimization by the household implies two first-order conditions: the labor-leisure decision and the Euler equation. The labor leisure decision, $v_{N,t} = (1-\tau_t)(1-\kappa\mu_t)u_{C,t}$, represents the tradeoff between consuming an additional unit and working an extra hour. Taxes $\tau_t$ and financial autarky $\mu_t$

[15] For a more detailed models of partial default see Adam and Grill (2017) and Arellano et al. (2023).

create a wedge between the first best allocation of consumption and hours, $v_{N,t} = u_{C,t}$. For a given tax rate and default decision the labor-leisure decision pins down labor supply. The Euler equation describes households demand for defaultable liquid bonds:

$$\frac{u_{C,t}}{R_t} = \beta \sum_{s^{t+1}} \Omega_{t+1|t}(1-\delta_{t+1})[u_{C,t+1} + \frac{w_{b,t+1}}{Y_{t+1}}]. \tag{43}$$

The supply of government debt $B_t$ and the households demand for defaultable liquid assets pins down the equilibrium interest rate $R_t$. While in financial autarky policymakers cannot issue bonds and the interest rate is undefined.

### E.1.3 Equilibrium

A *feasible government policy* is a government policy $p_t = \{\tau_t, \delta_t, T_t, B_t\}$ which respects (i) the Labor Laffer curve and (ii) the lower bound on lump-sum transfers $T_t \geq 0$. For a given feasible government policy, a *competitive equilibrium* is a sequence $\{C_t, N_t, R_t\}$ that satisfies (i) optimality for households (ii) optimality for firms (iii) market clearing and (iv) the government's budget. The *policymaker's problem* is to maximize household welfare (equation 42) over all competitive equilibrium. I only consider Markov perfect equilibrium that only depends on the relevant state variables.

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