

Optimal monetary and fiscal policy without fiscal backing*

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Job Market Paper

October 21, 2024

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Abstract

This paper studies optimal monetary and fiscal policy when Treasury is unable to provide optimal fiscal backing to the central bank. The central bank holds large reserves and incurs interest expenses. During periods when costs exceed earnings, the Federal Reserve does not receive transfers from Treasury to offset the losses. I analyze the optimal monetary and fiscal policy in a New-Keynesian model with central bank and Treasury, where the transfer of resources from Treasury to the central bank is constrained, but not vice versa. This lack of fiscal support implies: (i) the central bank, without fiscal backing, tolerates higher inflation in response to cost-push shocks, and this inflation response increases with the level of reserves; (ii) while the lack of fiscal support increases the volatility of the optimal inflation rate by 3%, the average optimal inflation rate is minimally affected; (iii) the welfare gains from fiscal support are small over the business cycle, but in the case of large shocks, a fiscal backstop reduces the welfare cost of the shock by 20%.

*I am deeply indebted to my advisor Ricardo Lagos for his invaluable guidance and support. I am grateful to Jaroslav Borovička, Venky Venkateswaran, Kosuke Aoki, Corina Boar, Mark Gertler, Simon Gilchrist, Nobu Kiyotaki, Virgiliu Midrigan, Tom Sargent, and Kenji Wada for insightful discussion.

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1 Introduction

A common assumption in conventional macroeconomic models of monetary-fiscal policy is a consolidated government budget (Sargent and Wallace, 1981). Treasury finances public expenditures through taxes and government bonds. Central bank issues money and reserves to provide liquidity. Under the assumption of the consolidated government budget, there is no need to distinguish between the Treasury's budget and the central bank's budget.

The starting point of this paper is to question the assumption of fully consolidated government budgets. Following the inflationary shock in 2022, the Federal Reserve incurred losses, effectively ending transfers between Treasury and central bank. Under the Federal Reserve Act, when profits exceed costs, Reserve Banks are required to remit excess earnings to the Treasury. However, the Federal Reserve is incurring significant interest expenses (5.5%) on large reserves (15% of GDP). These costs exceed earnings¹. When earnings are insufficient to cover these costs, Treasury does not compensate for the Federal Reserve's losses. Transfers between Treasury and central bank stop now. Conventional models of consolidated government budgets are inadequate for studying situations where the central bank's budget is not fully integrated with the Treasury's. This paper defines the government's budget as unconsolidated if and only if Treasury does not provide optimal fiscal support to central bank.

This paper studies the implications of the lack of optimal fiscal support for central bank on the monetary and fiscal policy. The government chooses policies to maximize household utility subject to implementable equilibrium conditions. The key novelty of my model is that 1. the government can issue two types of interest-bearing liabilities, reserves and government bonds, 2. a transfer from Treasury to central bank is constrained, while the reverse direction is not. Treasury receives resources from central bank to provide public expenditure. Central bank supplies reserves to the market, and when reserves are large, it reduces large reserves. However, this reduction is limited by the constrained transfers from Treasury. Facing this constraint, the government chooses the optimal policies.

Section 2 presents the sticky-price New Keynesian model, which includes Treasury and central bank. Households consume, work, and trade government bonds and reserves. Government bonds

¹The cumulative net loss from September 2022 to October 2024 is 210 billion dollars; 0.7% of GDP.

and reserves are saving technologies, and they also provide liquidity value. Firms follow the standard New Keynesian framework with adjustment cost, using labor as input and facing exogenous shocks to wage mark-ups (cost-push shocks) and productivity. A key feature of the model is that transfers from central bank to Treasury are subject to a lower bound, limiting the optimal resource allocation between the two. Treasury finances public expenditures but can only impose distortionary taxes on firms' sales. Treasury uses government bonds to smooth tax impacts. In addition to this standard tax smoothing mechanism, my model includes the remittance from central bank, allowing the Treasury to rely on these transfers to fund public expenditures. Central bank supplies reserves to the market and pays interest on those reserves. To meet the demand for reserves, the central bank must satisfy the downward sloping demand curve, which means that larger reserves require a lower price for reserves, i.e., a higher nominal interest rate. When reserves are abundant, the central bank seeks to reduce reserves; however, direct transfers from Treasury are constrained by a lower bound.

Section 3 describes the optimal policy problem under discretion. An agent, referred to as the 'government,' simultaneously decides fiscal policy and monetary policy to maximize the utility of households subject to the equilibrium conditions. Two models are defined: "the consolidated model" and "the unconsolidated model". The consolidated model assumes no constraints on remittances and follows a standard New Keynesian framework with a fully integrated government budget: Treasury and central bank budgets are consolidated. Central bank is fiscally backed by Treasury, allowing interest payments by the central bank to be financed through transfers from the Treasury. In contrast, the unconsolidated model is a model with a constraint on transfer from Treasury to central bank, meaning the two budgets are not fully integrated. The key deviation in my model from the standard New Keynesian framework lies in this constraint on resource allocation. The aim of this research is to compare the equilibrium outcomes between the unconsolidated model and the consolidated model.

The role of transfers is to relax one budget constraint by tightening the other. When the Treasury's budget is tightened, central bank can transfer funds to relaxed the Treasury's budget pressure. Conversely, if the central bank faces high interest expenses and its budget is tightened, it will need funds from the Treasury. In the unconsolidated model, the resource allocation constraint prevents the central bank from reducing large reserves. To induce households to hold more reserves, the price of reserves must fall, i.e. the nominal interest rate must rise. A higher nominal interest

rate affects real allocations, which explains why the lack of fiscal backing imposes significant costs.

Section 4 describes solution methods and calibration. Section 5 studies the dynamics of the economy upon a positive cost-push shock and a negative productivity shock. For a cost-push shock, motivated by the large inflationary shock in 2022, I compare the dynamics in the consolidated model and the unconsolidated model. The first main finding is that central bank in the unconsolidated model tolerates the higher inflation rate. In the consolidated model, a cost-push shock raises marginal costs. To bring the marginal product closer to high marginal cost, the government reduces a tax rate on sales. This leads to a drop in tax revenue, tightening the Treasury's budget, but Treasury still needs to finance public expenditures. Central bank supports Treasury by issuing more reserves, creating more resources, and remitting them to Treasury. In the unconsolidated model, however, the central bank knows that it cannot reduce excess reserves through remittances, limiting its ability to generate resources by issuing additional reserves. As a result, the support for Treasury from central bank is reduced. Consequently, the tax reduction is smaller in the unconsolidated model, leading to a higher inflation rate in response to the cost-push shock.

In response to a negative productivity shock, the "divine coincidence" (Blanchard and Galí, 2007) no longer holds. A negative productivity shock increases marginal costs, and lower consumption becomes optimal for households. The central bank raises the nominal interest rate to counter this. In the consolidated model, the central bank raises the nominal interest rate sufficiently, aligning the policy rate with the natural interest rate. As a result, both the output gap and the inflation response shrink to zero. In the unconsolidated model, however, the central bank cannot raise the interest rate enough due to limited funds to cover interest expenses. Since the nominal interest rate is not raised adequately, consumption falls less than in the consolidated model, leading to a stronger inflation response and non-zero output gap.

Section 6 examines the dynamic properties of optimal policies over the business cycle. I analyze the volatility of the optimal inflation rate and tax rate (Schmitt-Grohé and Uribe, 2004; Chari, Christiano, and Kehoe, 1991). A key question addressed is how much inflation the government uses to inflate nominal government liabilities and how effectively it can smooth taxes over time. While the government can utilize inflation volatility to inflate nominal liabilities, such volatility incurs costs due to adjustment frictions. The main finding is that the lack of fiscal backing increases the volatility of the optimal inflation rate and tax rate. The central bank can issue more reserves

and support the Treasury's budget through remittances, enabling the Treasury to better smooth tax distortions by relying on these transfers. In the unconsolidated model, however, the central bank transfers less to the Treasury because the excess reserves generated from increased transfers cannot be reduced. As a result, the central bank's capacity to support Treasury in smoothing taxes is limited in the unconsolidated model, leading to greater tax volatility. Additionally, inflation becomes more volatile because the variability in the sales tax rate contributes to fluctuations in the marginal product. This increased volatility in marginal products translates into greater inflation rate fluctuations, as the changes in marginal costs are directly linked to the inflation rate.

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While the volatility of the inflation rate and tax rate increases, what happens to their means? The second key finding is about the stochastic steady states. The average optimal inflation rate in the unconsolidated model is 0.05% higher than in the consolidated model. Although the lack of fiscal backing impacts volatility in the unconsolidated model, it affects the stochastic steady state to a much less. The absence of fiscal backing influences the government's tax smoothing motive, which affects the second moment but not the first moment. The central bank can issue reserves, generate resources, and remit them to the Treasury, enhancing the Treasury's ability to smooth taxes; an aspect related to the second moment. When remittances are constrained, the second moment is impacted more significantly. However, the first moment is affected to a lesser degree because the tax smoothing motive does not influence the first moment.

Section 7 evaluates the welfare gain of fiscal backing for the central bank. The central banks including Bank of England and Reserve Bank of New Zealand incur their loss and Treasury pays to offset the losses. Central bankers show concerns for this policy because of financial independence reason, but others show the advantage because it increases central banks net worth ². This paper evaluates the gain of the fiscal backing for the central bank based on only a normative perspective. The first finding is that the welfare gain of fiscal backing for the central bank over the business cycle is small, less than 0.01% of consumption equivalence. Although the volatility of macroeconomics variables are affected by the fiscal backing, the mean is hardly affected. Since the first-moment matters for the welfare analysis, the welfare gain of fiscal backing is small.

²See Floden (2022) and Bullock (2022)

Related literature First, this article is closely related to large literature on monetary-fiscal policy interactions (Sargent and Wallace (1981); Leeper (1991); Sims (1994); Woodford (2001), among others). Sargent and Wallace (1981) is a seminal work that highlights the implications of a consolidated government budget, showing that the Treasury's budget constraints the central bank's ability to control inflation. Since then, the assumption of a consolidated government budget constraint has become a common framework in the literature, as seen in Leeper (1991); Woodford (2001); Schmitt-Grohé and Uribe (2004); Benhabib, Schmitt-Grohé, and Uribe (2002). This paper questions that assumption by considering the current reality, where resource allocation between the central bank and the Treasury has effectively stopped.

More recent studies have focused on the unconsolidated budgets of Treasury and central bank. These papers study various issues, including central bank solvency (Hall and Reis, 2015; Bassetto and Messer, 2013; Bassetto and Sargent, 2020), price determinacy (Del Negro and Sims, 2015; Benigno and Nisticò, 2020), the effectiveness of central bank asset purchase policies (Benigno, 2020), the impact of helicopter drops (Amador and Bianchi, 2023), the projected path of central bank net worth and earnings (Christensen, Lopez, and Rudebusch, 2015; Carpenter, Ihrig, Klee, Quinn, and Boote, 2018), and the empirical relationship between central bank losses or negative net worth and monetary policy conduct (Stella, 2005, 2008; Goncharov, Ioannidou, and Schmalz, 2023). This paper is the first to study the macroeconomic implications of the constraint on transfers from the Treasury to the central bank. Also, while the literature is in a positive perspective, this is the first paper to study the unconsolidated government budget in normative perspective.

An important novelty of this research is the optimal policy and welfare in scenarios where the central bank's budget is balanced without fiscal backing from the Treasury. Previous literature has focused on estimating how much seigniorage would be required to balance the central bank's budget, finding that the required inflation rate is substantial (Del Negro and Sims, 2015). In contrast, this paper examines a situation in which the central bank can balance its budget not only through inflation, but also by adjusting the nominal interest rate and asset purchase policy. The results show that while the welfare cost of not having a fiscal backing is small during a typical business cycle, it becomes significantly larger in the face of a larger shock.

Moreover, the literature lacks a comprehensive analysis of fiscal policy within the optimal policy framework. While existing studies tend to focus on the monetary side and keep the fiscal

side simple, this paper models tax smoothing motive and shows that central bank policies influence optimal fiscal policies, such as taxation and government bond issuance. In this respect, this paper follows the conclusions of the traditional monetary-fiscal policy literature, which emphasizes that monetary and fiscal policies constrain each other (Sargent and Wallace (1981); Leeper (1991), and more recently, Bianchi (2013); Bianchi and Ilut (2017)).

The closest papers are Berriel and Bhattarai (2009) and Amador and Bianchi (2023). Berriel and Bhattarai (2009) studies the optimal policy in New Keynesian framework. While Berriel and Bhattarai (2009) assumes that the government's objective function directly includes the central banks loss, this paper does not directly include the loss from destabilized central bank net worth. Rather, the government in my model cares central bank balance sheet because the marginal utility of reserves decreases when reserves is excess. The benefit of this specification is that the critical parameter that determines the government weight on the motive to reduce the excess reserves are calibrated relatively easily, the slope of demand curve.

Amador and Bianchi (2023) is the only paper that models the constraint on resource allocation from the Treasury to the central bank, focusing on helicopter drops during a liquidity trap from a positive perspective. It finds that helicopter drops can be an effective stabilization policy in a liquidity trap when the central bank faces constraints on resource allocation. In contrast, this paper approaches monetary-fiscal policy from a normative perspective, examining the optimal policy responses under these constraints.

Second, this paper is related to literature on central bank balance sheet policies. The literature focuses on the effectiveness of central bank's asset policies (For theoretical papers, Gertler and Karadi (2011); Woodford (2011) among others. Empirical papers, Krishnamurthy and Vissing-Jorgensen (2011); D'Amico and King (2013)). While there is an extensive research on asset purchase policy, there are less papers on liability policies.

For liability policies, there is a study of macroeconomic implications on large reserves that this paper is related to (Poole, 1968; Cochrane, 2014; Reis, 2016; Ennis, 2018; Williamson, 2019; Arce, Nuno, Thaler, and Thomas, 2020; Bianchi and Bigio, 2022). Ennis (2018) finds that price level indeterminacy may arise when banks hold excess reserves. Reis (2016) finds that only the IOR and not the size of the balance sheet has an effect on inflation. Arce et al. (2020) proposes New-Keynesian equilibrium model to compare the pre-crisis lean balance sheet regime and the

post-crisis floor system with a large balance sheet. Bianchi and Bigio (2022) studies credit channel of monetary policy in a model where banks manage liquidity facing frictions in the interbank market.

The contribution of this paper lies in examining the implications of excess reserves within the standard New Keynesian framework. Unlike Afonso and Lagos (2015), which delves into the microstructure of interbank lending and payments, this paper simplifies the demand for reserves by introducing them directly into household utility. This paper incorporates a general equilibrium New Keynesian model, with a particular focus on (i) fiscal policy, including distortionary taxes and government bonds, and (ii) transfers between the Treasury and the central bank. While much of the literature on large reserves overlooks fiscal considerations, this paper emphasizes the importance of fiscal policy and how fiscal backing for the central bank influences fiscal decisions.

The closest works in this literature are Berentsen, Marchesiani, and Waller (2014) and Berentsen, Kraenzlin, and Müller (2018), as both highlight that the implications of excess reserves critically depend on the level of fiscal support provided to the central bank. Berentsen, Kraenzlin, and Müller (2018) finds that when the central bank lacks fiscal support, reducing reserves is the optimal policy. They compare the floor system and the channel system from a normative perspective and conclude that the floor system is superior when there is fiscal backing. While Berentsen, Kraenzlin, and Müller (2018) explores regimes of full fiscal support and no fiscal support, this paper assumes a lack of *optimal* fiscal support, where there is no constraint on transfers to the Treasury, but transfers to the central bank are constrained. This assumption more closely aligns with the current policy of the Federal Reserve.

While many empirical literature focuses on asset-induced portfolio balance effects on central bank balance sheet policies, Christensen and Krogstrup (2019) presents empirical evidence of a reserve-induced transmission channel of central bank's balance sheet policies to long-term interest rates. Reserve-induced effects are independent of the assets purchased and run through the impact of reserve expansions. They analyze the reaction of Swiss long-term government bond yields to announcements by the Swiss National Bank to expand central bank reserves without acquiring any long-lived securities. They find that long-term yield declines following the announcements. Their findings are consistent with this paper's mechanism that the increase of quantity of reserves by paying interest on reserves change the nominal interest rate even without purchasing assets by

central bank.

Third, this paper relates to the literature on the optimal monetary and fiscal policy. The literature focuses on (i) the optimal volatility and persistence of inflation (Chari, Christiano, and Kehoe, 1991; Schmitt-Grohé and Uribe, 2004; Siu, 2004; Chugh, 2006, 2007), (ii) temptation to erode government nominal liability by inflation (Schmitt-Grohé and Uribe, 2004; Niemann, Pichler, and Sorger, 2013; Leeper, Leith, and Liu, 2021) (iii) the stochastic behavior of debt (Barro, 1979; Lucas and Stokey, 1983; Aiyagari, Marcet, Sargent, and Seppälä, 2002; Schmitt-Grohé and Uribe, 2004; Benigno and Woodford, 2003), studying if the debt follows the random-walk property regardless of the process of shock. The literature focuses on the consolidated government budget. Also, the papers abstract the reserves, another type of interest-bearing government liabilities.

This paper casts light on the unconsolidated government budget that is more consistent with constraints that central banks face. Also, I model the demand for reserves, instead of money, in line with the liquidity value of reserves and government bonds (Krishnamurthy and Vissing-Jorgensen, 2012).

2 Model

This section describes the model and defines the equilibrium. The model is a standard New Keynesian framework incorporating both the Treasury's and the central bank's budget constraints. Before presenting the model, I define key terminology. "Government" refers to an agent that chooses both monetary and fiscal policies, with the objective of maximizing household utility. The problem for Government is defined in section 3. The "Treasury" and "central bank" can be considered to be subsets of the government, each with its own budget constraint. The Treasury collects taxes, provides public expenditure, and issues liabilities: "government bonds". Central bank issues another form of liability: "reserves". Two types of liabilities, reserves and government bonds, are distinguished by issuers.

2.1 Households

The representative households choose consumption, labor supply, and the holdings of one period risk free nominal bond (reserves) and long-duration risk free nominal bonds (government bonds)

to maximize the expected discounted sum of the future period utilities. The households like consumption and dislikes labor. The households get convenience yield from trading both reserves and government bonds. Households maximizes

$$\max_{\{C_t, N_t, D_t, B_t^H\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{1}{1+\nu} N_t^{1+\nu} + \frac{\chi_1}{1-\gamma_1} \left(Q_t^C \frac{D_t}{P_t} \right)^{1-\gamma_1} + \frac{\chi_2}{1-\gamma_2} \left(Q_t^T \frac{B_t^H}{P_t} \right)^{1-\gamma_2} \right] \quad (1)$$

where C_t is a Dixit-Stiglitz aggregate consumption of a continuum of differentiated goods,

$$C_t \equiv \left[\int_0^1 c_t(i)^{\frac{\theta}{\theta-1}} di \right]^{\frac{\theta-1}{\theta}} \quad (2)$$

with an elasticity of substitution equal to $\theta > 1$. Also, N_t is the labor supply, Q^C is the price of the reserves, D is the quantity of reserves, Q^T is the price of government bonds, B^H is the quantity of government bonds held by the households.

Each differentiated good is supplied by a monopolistically competitive producer. The goods in each industry j are produced using labor that is specific to that industry. Labor supply is aggregated at firm level.

$$N_t = \int_0^1 N_t(i) di. \quad (3)$$

Households receive a convenience yield from holding reserves and government bonds. The convenience yield from reserves can be interpreted as the expected savings in transaction costs for commercial banks, as they do not need to sell loans to manage deposit outflows. Under an assumption that households own these commercial banks, they value the reduction in transaction costs that benefits them. An example of the convenience yield from holding government bonds is that Treasury securities lower the costs associated with transacting in less liquid securities, such as corporate bonds.³ Convenience yield terms allows me to match the steady-state value of reserves and government bonds, which critically influences interest expenses and is essential for quantitative analysis.

The budget constraint is

$$P_t C_t + Q_t^C D_t + Q_t^T B_t^H = D_{t-1} + (1 + \rho^T Q_t^T) B_{t-1}^H + w_t N_t + P_t \Phi_t, \quad (4)$$

³For more discussion of convenience yield, see Lopez-Salido and Vissing-Jorgensen (2023) for reserves and Krishnamurthy and Vissing-Jorgensen (2012) for government bonds among others.

where Φ_t is the the profit. In period t , the households buy government bonds, B^H , at price Q_t^b that pay a declining coupon of ρ^{Tj} dollars in period $j+1$, where $0 \leq \rho \leq \beta^{-1}$. A measure of the duration of the bond is given by $(1 - \beta\rho^T)^{-1}$. The households bring nominal bonds of $(1 + \rho^T Q_t^b)B_{t-1}^H$ into period t .

2.2 Firms

There is a continuum of goods producers indexed by $i \in [0, 1]$. Firms use labor as inputs and produce imperfectly substitutable goods according to a linear production function. Each firm sets the price of its own good to maximize the expected discounted sum of future profits.

Firms i face three constraints, a linear production function,

$$y_t(i) = A_t N_t(i), \quad (5)$$

where A_t is the aggregate productivity.

Second, firms face a demand curve of the form

$$y_t(i) = Y_t \left(\frac{p_t(i)}{P_t} \right)^{-\theta}, \quad (6)$$

where the aggregate demand is defined as

$$y_t(i) = \left(\int_0^1 y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}} \quad (7)$$

Third, quadratic adjustment costs in changing prices, as in Rotemberg (1982), are defined as

$$\frac{\varphi}{2} \left(\frac{p_t(i)}{p_{t-1}(i)} - 1 \right)^2 P_t Y_t, \quad (8)$$

where φ deciplines the degree of nominal price rigidity.

A firm i sets its price $p_t(i)$ in period t to maximize the expected discounted sum of future profits.

$$\max_{p_t(i)} E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \left((1 - \tau_t) p_t(i) y_t(i) - \mu_t^w w_t N_t(i) - \frac{\varphi}{2} \left(\frac{p_t(i)}{p_{t-1}(i)} - 1 \right)^2 P_t Y_t \right) \quad (9)$$

where Λ_t is the stochastic discount factor given by

$$\Lambda_t \equiv \frac{C_t^{-\sigma}}{P_t} \quad (10)$$

The stochastic discount factor measures the marginal value of an additional unit of profits to the household. τ_t is the tax on sales levied by the Treasury. μ_t^w captures the shock to wage mark-up. One possible interpretation of the wage markup shock is that it represents the bargaining power of labor unions.

The cost-push shock and productivity follow the AR(1) process.

$$\mu_t^w = \bar{\mu}^w + \rho^w(\mu_{t-1}^w - \bar{\mu}^w) + \varepsilon_t^w. \quad (11)$$

$$A_t = \bar{A} + \rho^a(A_{t-1} - \bar{A}) + \varepsilon_t^a. \quad (12)$$

There is no heterogeneity in the time-zero prices across firms. That is $p_{-1}(i) = P_{-1}$ for a given constant P_{-1} . The first-order condition implies the non-linear Phillips curve

$$N_t C_t^{-\sigma} (\varphi(\pi_t - 1)\pi_t A_t - (1 - \theta)(1 - \tau_t)A_t - \theta\mu_t^w N_t^\nu C_t^\sigma) = \beta E_t [A_{t+1} N_{t+1} C_{t+1}^{-\sigma} \varphi(\pi_{t+1} - 1)\pi_{t+1}]. \quad (13)$$

2.3 Treasury and central bank

The government's problem is introduced in the next section. This section describes a set of restrictions that government faces. Government faces three constraints: Treasury's budget, central bank's budget, and a constraint on transfer from Treasury to central bank.

The Treasury plays a role of supplying exogenous, stochastic, and useless public expenditures G_t . Aggregate public expenditure takes

$$G_t \equiv \left(\int_0^1 G_t(i)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}} \quad (14)$$

such that the government demand for goods is given by

$$G_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon} G_t \quad (15)$$

The exogenous public expenditure follows AR(1) process,

$$G_t = \bar{G} + \rho^g(G_{t-1} - \bar{G}^w) + \varepsilon_t^g. \quad (16)$$

The expenditures are financed by sales tax, issuance of the government bonds, and the remittance from the central bank. The Treasury's budget constraint is given by

$$Q_t^T B_t^T + \tau_t P_t Y_t + P_t H_t = P_t G_t + (1 + \rho^T Q_t^T) B_{t-1}^T. \quad (17)$$

$\tau_t Y_t$ is the distortionary tax on sales. H_t is the remittance from central bank to Treasury. A positive H_t implies that the central bank transfers its profit to the Treasury.

The central bank's role is to supply reserves that households appreciate. In addition to reserves, the central bank also trades government bonds. The central bank budget constraint is

$$Q_t^C D_t + (1 + \rho^T Q_t^T) B_{t-1}^C = D_{t-1} + Q_t^T B_t^C + P_t H_t, \quad (18)$$

where D_t is reserves and H_t is the remittance from central bank to Treasury. B_t^C is the Treasury's bond issued by the central bank's asset.

The left-hand side of the budget constraint represents the income for central bank. Central bank generates revenue by issuing more reserves ($Q_t^C D_t$), income gains from asset holdings (B_{t-1}^C), and capital gains from asset holdings ($\rho^T Q_t^T B_{t-1}^C$). When the central bank raises the nominal interest rate, the price of reserves (Q_t^C) falls, requiring the issuance of more reserves. On the asset side, a lower nominal interest rate leads to a decline in asset prices, which results in a capital loss. This is reflected in the decline of Q_t^T in the term $\rho^T Q_t^T B_{t-1}^C$.

The right-hand side of the budget constraint represents expenditures for central bank. Expenditures consists of redemption of reserved (D_{t-1}), purchase of assets ($Q_t^T B_t^C$), and remittance to Treasury ($P_t H_t$).

Note that this budget constraint is mark-to-market. In reality, Federal Reserves and other central banks including Bank of Japan adopts book-value for calculating the value of assets, while Bank of England adopts mark-to-market. In my model, central bank

For the central bank's asset purchase policy, it is assumed that the constant fraction of Treasury bond is held by the central bank.

$$B_t^C = \alpha B_t^T \quad (19)$$

This assumption is to reduce the size of state-space. As I will describe in the next section, the model has four state variables: exogenous shock, reserves, total supply of government bonds, government bonds held by central bank. That brings computational difficulties. By assuming (19), the model has three state variables that allows the global solution.

A justification for this assumption is that the focus of this paper is central bank's liability side, not asset side. The central bank trades liability and assets. The focus of this paper is liability side,

so I endogenous the liability policy. In contrast, one of the purposes of the asset purchase policy is to stabilize the financial market (Gertler and Karadi, 2011). The financial stabilization is outside this model. I make the asset policy exogenous. Under this assumption, the asset purchase by the central bank is smooth over time. A sudden change in the asset purchase amount would destabilize the asset market.⁴ This assumption is consistent with the central bank's goal.

Finally, the government faces the constraint that prevents optimal resource allocation between the central bank and the Treasury. This constraint is one-sided. The Treasury can receive as much resource as it wants from the central bank. However, the central bank is constrained to receive resources from the Treasury for political reasons. Inequality constraint on the remittance

$$H_t \geq H^*. \quad (20)$$

H^* is a exogenous parameter. The model is consistent with the Federal Reserve's actual policy. When the cost exceeds the earnings, a so-called "deferred asset" is accumulated. "deferred asset" is a negative liability whose value is the cumulative value of the shortfall in earnings. Once the Fed returns to earning a positive net income, it will pay down the value of the deferred asset until it reaches zero, at which point the Fed will resume sending remittances to the Treasury. In 2024 October, the deferred asset is 210 billion dollars that is 0.7% of annual GDP.

The motivation for this constraint stems from "political reasons" from the Treasury's perspective. To cover the central bank's losses, the Treasury would need to raise taxes or issue additional debt, both of which are politically costly. Moreover, the central bank pays interest expenses to commercial banks, which are not perfectly competitive. If the Treasury decides to cover these interest expenses through taxation, it effectively redistributes income from households, including poorer ones, to commercial banks. This type of redistribution is difficult for the Treasury to justify politically.

From the central bank's perspective, requesting capital injections could help maintain a strong financial position and avoid a weakened balance sheet. However, there is concern that relying on parliamentary decisions for funding could threaten central bank independence⁵.

Note that the literature on the unconsolidated government budget already models remittance

⁴See literature on Taper Tantrum (Eichengreen and Gupta, 2015) about the cost of sudden change in central bank's asset purchase policy

⁵For actual comments from central bankers, see Floden (2022), where the Deputy Governor of the Riksbank expresses these concerns.

(Bassetto and Messer, 2013; Del Negro and Sims, 2015; Benigno and Nisticò, 2020; Benigno, 2020). However, no model has ever studied the constraint on remittance.

2.4 Market Clearing

Clearing of the goods i market requires the following.

$$y_t(i) = C_t(i) + G_t(i) + \frac{\varphi}{2} \left(\frac{p_t(i)}{p_{t-1}(i)} - 1 \right)^2 y_t(i). \quad (21)$$

$$Y_t(i) = A_t N_t(i) \quad (22)$$

In a symmetric equilibrium,

$$Y_t = C_t + G_t + \frac{\varphi}{2} (\pi_t - 1)^2 Y_t. \quad (23)$$

$$Y_t = A_t N_t \quad (24)$$

The clearing conditions for government bonds are

$$B_t^H + B_t^C = B_t^T \quad (25)$$

where government bonds are held by households and the central bank. Note that I impose an assumption that central bank holds α fraction of total supply of government bonds.

$$B_t^H = (1 - \alpha) B_t^T \quad (26)$$

$$B_t^C = \alpha B_t^T \quad (27)$$

There is also market clearing in reserves markets where reserves held by households evolves according to the central bank's budget constraint.

The price index is defined as

$$P_t \equiv \left[\int_0^1 p_t(i)^{1-\theta} di \right]^{\frac{1}{1-\theta}} \quad (28)$$

$$\pi_t \equiv \frac{P_t}{P_{t-1}}. \quad (29)$$

2.5 Equilibrium

Given the distribution of initial prices, $p_{-1}(i)$, stochastic processes, and the initial level of liabilities B_{-1}, D_{-1} , a competitive equilibrium of this economy consists of allocations $\{C_t, N_t, Y_{i,t}\}_{t=0}^{\infty}$, prices $\{p_t(i)\}_{t=0}^{\infty}$, and policy instruments $\{Q^C, Q^T, \tau, B_t, D_t\}_{t=0}^{\infty}$, such that

- allocations solve the problem of the household given prices and policies
- $p_t(i)$ solves the problem of firm i
- $p_t(i) = p_t(j)$
- The Treasury and central bank's budgets are satisfied
- all market clears.

3 The Optimal Policy Problem under discretion

This section outlines the optimal policy problem under discretion. The government makes decisions sequentially. Each period t , the government maximizes the utility of households by choosing $\{C_t, N_t, \Pi_t, Q_t^C, Q_t^T, b_t, d_t, \tau_t, H_t\}$ and the Lagrangian multipliers associated with the equilibrium conditions, taking as given the next period value and next policy functions. I define real value of reserves and government bonds, $b_t \equiv \frac{B_t}{P_t}$ and $d_t \equiv \frac{D_t}{P_t}$. The optimization is subject to the implementable equilibrium conditions.

$$V_t(s_t) = \max_{a_t} \frac{1}{1-\sigma} C_t^{1-\sigma} - \frac{1}{1+\nu} N_t^{1+\nu} + \frac{\chi_1}{1-\gamma_1} (Q_t^C d_t)^{1-\gamma_1} + \frac{\chi_2}{1-\gamma_2} ((1-\alpha) Q_t^T b_t)^{1-\gamma_2} + \beta E_t V_{t+1}(s_{t+1}), \quad (30)$$

where $s_t \equiv \{\mu_t^w, A_t, G_t, b_{t-1}^C, b_{t-1}^T\}$ and $a_t \equiv \{C_t, N_t, \Pi_t, Q_t^C, Q_t^T, b_t, d_t, \tau_t, H_t\}$.

Equilibrium conditions are

$$(\text{Euler for reserve}) \quad C_t^{-\sigma} Q_t^C = \beta E_t \left[\frac{C_{t+1}^{-\sigma}}{\pi_{t+1}} \right] + \chi_1 (Q_t^C d_t)^{-\gamma_1} Q_t^C \quad (31)$$

$$(\text{Euler for Treasury bond}) \quad C_t^{-\sigma} Q_t^T = \beta E_t \left[C_{t+1}^{-\sigma} \frac{1 + \rho^T Q_{t+1}^T}{\pi_{t+1}} \right] + \chi_2 ((1-\alpha) Q_t^T b_t)^{-\gamma_2} Q_t^T \quad (32)$$

$$\begin{aligned}
(\text{Firm FOC}) \quad N_t C_t^{-\sigma} (\varphi(\pi_t - 1)\pi_t A_t - (1 - \theta)(1 - \tau_t)A_t - \theta\mu_t^w N_t^\nu C_t^\sigma) \\
= \beta E_t [A_{t+1} N_{t+1} C_{t+1}^{-\sigma} \varphi(\pi_{t+1} - 1)\pi_{t+1}].
\end{aligned} \tag{33}$$

$$(\text{Market Clearing}) \quad A_t N_t = C_t + \frac{\varphi}{2}(\pi_t - 1)^2 A_t N_t + G_t \tag{34}$$

$$(\text{Treasury Budget}) \quad Q_t^T b_t + \tau_t Y_t + H_t = G_t + (1 + \rho^T Q_t^T) \frac{b_{t-1}}{\pi_t}. \tag{35}$$

$$(\text{Central Bank's Budget}) \quad Q_t^C d_t + (1 + \rho^T Q_t^T) \alpha \frac{b_{t-1}}{\pi_t} = \frac{d_{t-1}}{\pi_t} + Q_t^T \alpha b_t + H_t \tag{36}$$

$$(\text{Remittance}) \quad H_t \geq H^* \tag{37}$$

$$(\text{Shocks}) \quad \mu_t^w = \bar{\mu}^w + \rho^w (\mu_{t-1}^w - \bar{\mu}^w) + \varepsilon_t^w. \tag{38}$$

$$A_t = \bar{A} + \rho^a (A_{t-1} - \bar{A}) + \varepsilon_t^a. \tag{39}$$

$$G_t = \bar{G} + \rho^g (G_{t-1} - \bar{G}^w) + \varepsilon_t^g. \tag{40}$$

Note that I impose central bank holds α fraction of total supply of government bonds. Government chooses only the total supply of government bonds. Then, bonds held by households and central bank is determined by equations (26) and (27).

The discretionary equilibrium is determined by the first-order conditions, expectations that are consistent with policy functions, and the exogenous process for shocks. The solution is the time-invariant Markov-perfect equilibrium policy rules that map states $\{\mu_t^w, A_t, G_t, b_{t-1}, d_{t-1}\}$ to optimal decisions for $\{C_t, N_t, \Pi_t, Q_t^T, Q_t^C, b_t, d_t, \tau_t, H_t\}$.

The government is constrained to behave in a time-consistent manner. The economic agents anticipate that the government faces this constraint and form expectations. However, the government can change the expectations by choosing state variables, government bonds and reserves. In rational expectation equilibrium, the expectations are formed based on the mapping that map endogenous variables to the state-space.

Define "the consolidated model" and "the unconsolidated model" "The unconsolidated model" is defined as the model where the government maximizes the utility of households subject to (31) - (40). The remittance from the Treasury to the central bank is constrained.

"The consolidated model" is defined as the model where H^* is low enough that the equation (37) never binds. Later, H^* is set to be $-\infty$ in quantitative exercises. The consolidated government

budget is given by substituting H_t in equation (35) into equation (36).

$$Q_t^C d_t + (1 - \alpha)Q_t^T b_t + \tau_t Y_t = \frac{d_{t-1}}{\pi_t} + (1 + \rho^T Q_t^T)(1 - \alpha)\frac{b_{t-1}}{\pi_t} + G_t. \quad (41)$$

In the consolidated model, the government maximizes household utility subject to equations (31)-(34), (38)-(40), and (41). In this setting, the optimal resource allocation between the central bank and the Treasury is always achievable. It is important to note that the consolidated model represents the optimal monetary-fiscal policy problem within a standard New Keynesian framework (Benigno and Woodford, 2003; Schmitt-Grohé and Uribe, 2004). The key differences from Benigno and Woodford (2003); Schmitt-Grohé and Uribe (2004) are as follows: (1) while my model considers optimal policy under discretion, those papers analyze policy under commitment; (2) my model includes reserves as interest-bearing liabilities, whereas those papers include money.

Intuition The key ingredients of the model is the optimal resource allocation between the central bank and the Treasury, a remittance. A insight is generated by considering the first-order conditions for remittance in the consolidated model,

$$\lambda^C = \lambda^T, \quad (42)$$

where λ^C is Lagrangian multiplier associated with the central bank's budget, and λ^T is that of Treasury. A remittance equates the tightness of budget for the central bank and the Treasury. Consider a positive public expenditure shock. Expenditure can be financed by tax, but volatile tax reduces the utility of households, so the government wants to smooth tax by issuing liability. The households have the capacity to absorb limited amount of government bonds because the marginal value of liquidity of government bonds decrease as the Treasury issues more government bonds. The central bank issues more reserve and remit resources so that it finances public expenditure.

In the unconsolidated model, the inequality constraint can be binding. The central bank's budget constraint is more tightened than Treasury's budget constraint,

$$\lambda^C > \lambda^T. \quad (43)$$

4 Solution method and calibration

4.1 Solution method

Two reasons necessitate the use of global solution methods. The first is the presence of an occasionally binding constraint on remittance. Second, the state variables in the model include reserves and government liabilities. The model's steady-state depends on the derivative of expectations with respect to reserves and government liabilities. These derivatives are numerical objects that are part of the model solution, making the steady-state a priori unknown.

I use the collocation method with time iteration. A grid of N interpolation nodes is defined over the state space (s_t, b_t, d_t) , where s_t represents the exogenous shock. Due to the size of the state space, I include one shock at a time, chosen from cost-push, productivity, or public expenditure shocks. This model has three state-variables. The expectation terms in the Euler equations for reserves and government bonds, and New Keynesian Philips Curve

$$E_t \left[\frac{C_{t+1}^{-\sigma}}{\pi_{t+1}} \right] \quad (44)$$

$$E_t \left[C_{t+1}^{-\sigma} \frac{1 + \rho^T Q_{t+1}^T}{\pi_{t+1}} \right] \quad (45)$$

$$E_t [A_{t+1} N_{t+1} C_{t+1}^{-\sigma} \varphi(\pi_{t+1} - 1) \pi_{t+1}] \quad (46)$$

are evaluated at each interpolation N nodes using M node Gaussian-Hermite quadrature. My numerical algorithm is as follows

Step1: Guess initial policy functions for choice variables at the interpolation nodes N .

Step2: At each interpolation nodes N , compute the expectations (44)-(46) implied by the current guessed policy functions. Then, using the first-order conditions of the optimal policy problems, I derive a new guess for the policy functions. The first-order conditions involve the numerical derivative of the expectations (44)-(46) with respect to b_t and d_t . In consolidated model, the new policy functions are obtained. In the unconsolidated model, if $H_t < H^*$, set $H_t = H^*$ and solve for the choice variables. This delivers a new guess.

Step3: Compute the expectations given the new policy functions. Repeat step2 until the guessed policy functions and new policy functions are converged.

This paper focuses on optimal policy under discretion. Although it would be interesting to solve for the optimal policy under commitment, doing so would involve solving a model with six state variables: the shock, reserves, government bonds, and three Lagrange multipliers for the forward-looking equations (Marcet and Marimon, 2019). This significantly increases computational complexity, making it highly challenging.

4.2 Calibration

I calibrate my model to the US economy. The time unit is quarter. The calibration table is summarized in table 1. Some parameters are commonly used in the New Keynesian literature.

I set $\beta = 0.995$, which implies a 2% annual real interest rate. The intertemporal elasticity of substitution is set to $\frac{1}{2}$, a value commonly found in the literature. The Frisch elasticity of labor supply is fixed at $\frac{1}{7}$, while the elasticity of substitution between intermediate goods is 10, implying a monopolistic markup of 10%. The price adjustment cost parameter is set at 100. The coupon decay parameter, $\rho^T = 0.95$, corresponds to an average debt maturity of around 5 years, consistent with U.S. data (Leeper and Zhou, 2021).

The parameters that decides the convenience of reserves and government bonds are chosen to match the steady-state value of reserves and bonds. Reserves are matched to 15% of GDP. The recent level of government liabilities in data is 120% of GDP, and the convenience yield is not enough to match high level of government liabilities. I match the 30% of GDP that is the average of 1970-2020 in US data.

The fraction of government bonds held by the central bank is calibrated at 0.4 to match the asset-to-liability ratio. In the data, the Federal Reserve's asset-to-liability ratio is approximately 1. The parameter α is set at 0.4, which is higher than the value observed in the data (0.15). This discrepancy arises because, in reality, the Federal Reserve holds assets other than government bonds, such as Mortgage-Backed Securities and government-sponsored enterprise fixed assets, which are not included in this model. If I were to set $\alpha = 0.15$ to match the data and align the size of reserves in the model with the observed values, the size of the central bank's assets would fall significantly below its liabilities. This mismatch would alter the quantitative results, particularly because the model needs to capture both the capital loss on the asset side and the interest expense on

Table 1: Calibration.

Variable	Value	Description	Target	Model	Data
β	0.995	Discount factor	-	-	-
σ	2	Risk aversion	-	-	-
ν	7	Frisch Elasticity	Frisch Elasticity	1/7	-
θ	10	Elasticity of substitution among goods	Mark up	7%	-
ϕ	100	Price adjustment cost	Slope of NKPC	0.05	-
ρ^T	0.95	Duration of Treasury	Average Maturity	5 years	5 years
χ_1	0.0012	Utility from reserve	Steady-state reserve	15% of GDP	15% of GDP
χ_2	0.002	Utility from Treasury bond	Steady-state Treasury	30% of GDP	120% of GDP
γ_1	1.7	Curvature of utility from reserve	The elasticity of price to reserve supply	-0.2	0.2
γ_2	1.5	Curvature of utility from government bonds	The elasticity of price to government bonds supply	-0.1	-0.1
α	0.4	CB's asset holding	Asset/liability	1	1
H^*	-0.01	Lower bound on remittance	-	-	-

reserves. To avoid this issue, I set $\alpha = 0.4$, ensuring that the asset-to-liability ratio is approximately 1, consistent with the data.

The parameters that discipline the curvature of utility from reserves and government bonds, γ_1, γ_2 , are calibrated so that the elasticity of price to quantity in data matches that in the model following Krishnamurthy and Vissing-Jorgensen (2012). The details are discussed in Appendix A.

5 Responding to shocks

This section describes how the policy makers respond to shocks, a positive-cost push shock and negative productivity shock under the consolidated model and unconsolidated model.

5.1 Cost-push shock

The first exercise is to show the dynamics after the cost-push shock. The purpose of this exercise is to simulate the difference between the consolidated and unconsolidated model, that is the impact of the lack of fiscal backing. This exercise is motivated by 1. a large inflationary shock in 2022 2. large reserves that central bank holds when the shock hits. Corresponding to each motivation, I simulate the dynamics after a positive cost-push shock and the economy starts from large reserves when the shock hits.

Figure 1 plots the outcomes following a rise in the wage markup μ^w by 8%. The horizontal axis is the quarters. The blue line represents the outcomes in the consolidated model. The red line represents the outcomes in the unconsolidated model. The initial conditions for the state-variables are reserves and government bonds. The level of initial reserves are high, 90th percentile of simulated economy. The level of government bonds are the steady-state level. Note that the economy does not start from the steady-state, so the variable moves even without the cost-push shock. I did not net out

First, I describe what the government chooses policies in the consolidated model. Under the optimal policy, the government decreases the tax rate on sales to offset the increase of marginal cost. What the government wants to do is to make the marginal product closer to the marginal cost. The marginal cost increases upon the cost-push shock. The government levies taxes on sales, so the government can increase the marginal product by decreasing the tax rate. As a result of low tax rate, the tax revenue drops, but the Treasury needs to finance the public expenditure. The Treasury issues government bonds to finance public expenditure. The Treasury supplies more government bonds. From the central banks' perspective, the central bank helps Treasury's budget by issuing reserves, creating more resources, and sending resources to the Treasury. The central bank supplies more reserves after $t = 2$. However, upon the shock, the central bank holds large reserves. The central bank receives resources to reduce the level of reserves at $t = 1$. Therefore, reserves decline upon the shock, and then, increase.

For remittance, at $t = 1$, it takes a negative value, that is, Treasury sends and central bank receives. This is to reduce large reserves. After $t = 1$, the remittance is close to zero and flat. This is because two effects offset each other. The first is that central bank issues more reserves and send resources to Treasury. The second is that central bank needs to purchase more government bonds as Treasury issues more bonds. For central bank to purchase assets, the central bank needs to receive resources from the Treasury. These two effects offset each other. For consumption and inflation, the government cannot fully offset the cost-push shock, so the consumption drops and inflation rate increases. The price of reserves and government bonds drops, that is the increase of nominal inflation rate. This is to alleviate the trade-off between output and consumption.

In summary, the role of central bank is to help Treasury to do tax break upon the shock. Central bank can create resources by issuing reserves, so central bank helps Treasury by sending resources

to Treasury.

Next, I describe the dynamics in the unconsolidated model. The key results are that the inflation rate is higher and output drops more. This is because the government cannot reduce the tax rate sufficiently, so the high marginal cost reduces the output and pass-through to the inflation rate. Figure 1 shows that the tax rate does not drop in the unconsolidated model as much as in the consolidated model. Why does the government cannot reduce the tax rate enough? From the central bank perspective, it does issue reserves enough. Figure 1 shows that reserves in consolidated model increases after $t = 2$ to send resources to the Treasury. Reserves in the unconsolidated model does not increase a lot. The issuance of reserves in the unconsolidated model is smaller. This is because the large reserves cannot be reduced by remittance from the Treasury. If central bank issues more reserves, large reserves should be reduced later by remittance. This is not possible in the unconsolidated model. The issuance of reserves in the unconsolidated model is smaller. Fewer issuance of reserves means that the resource allocation from central bank to Treasury is smaller in the unconsolidated model. As a result, the government cannot use tax rate to offset the cost-push shock. The central bank tolerates a higher inflation rate. Inflation rate in the unconsolidated model responds more by 1.3%. Consumption drops more by 0.07%. Given that consumption decreases by 0.8% while inflation rises by 0.4% in consolidated model, the difference between the consolidated and unconsolidated model is significant.

In summary, the central bank does not help Treasury's budget enough in the unconsolidated mode because central bank does not create resources by issuing more reserves. Tax break is not enough in the unconsolidated model. The lack of *fiscal* backing impacts *fiscal* policy.

One thing to note is that, in the unconsolidated model, consumption drops more and inflation rate increases more. This is because tax rate (fiscal policy) is constrained, not because nominal interest rate is constrained. If central bank does not increase nominal interest rate enough, consumption drops less and inflation rate increases more. The opposite is true.

5.2 Productivity shock

The second exercise compares the dynamics of the two models after a negative productivity shock. The dynamics following a negative productivity shock are of interest in their own right (Blanchard

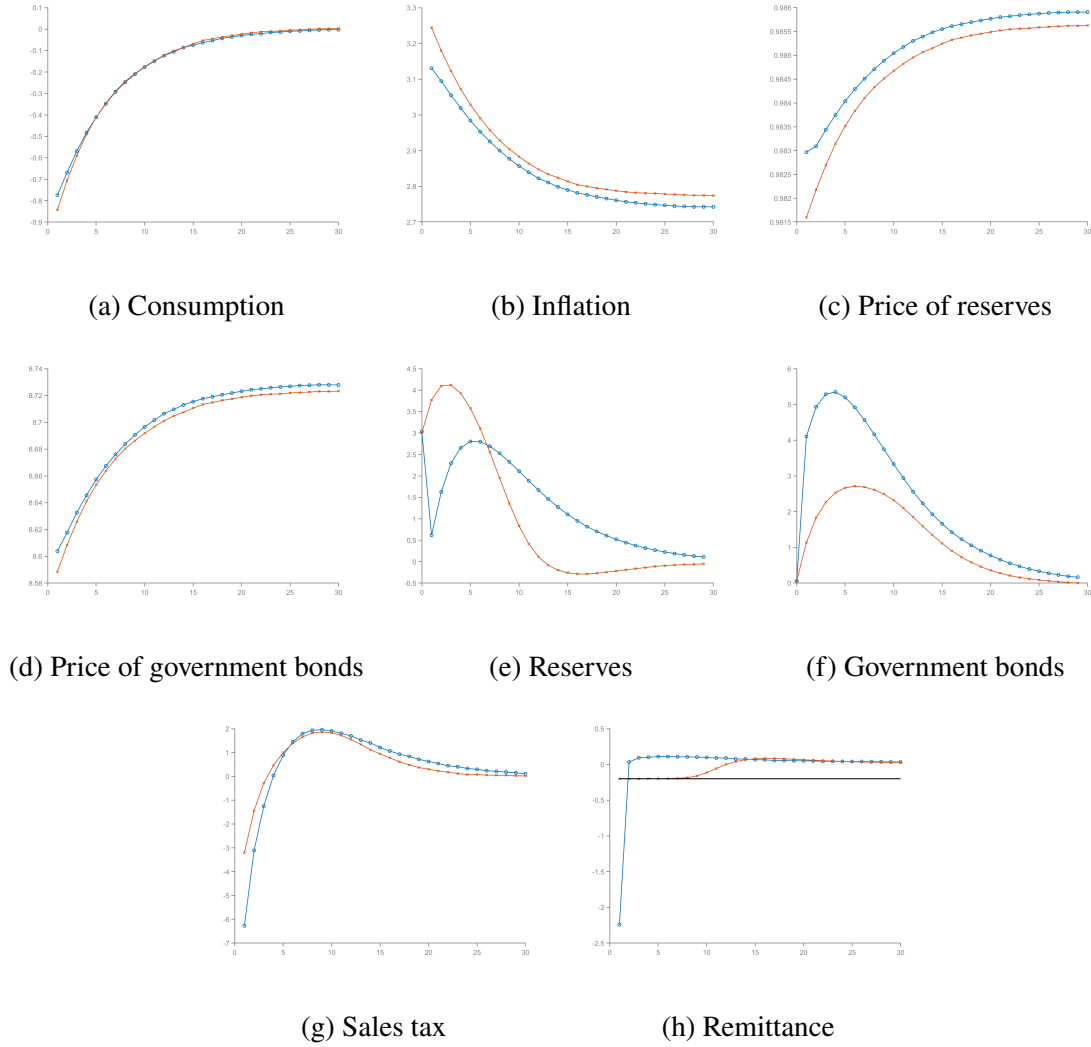


Figure 1: Cost-push shock

Note: This figure shows the dynamics of key variables upon the positive wage markup shock by 8%. The horizontal is quarters. The vertical lines for consumption, prices of reserves, prices of government bonds, reserves, government bonds are the steady-state deviation represented by percent. The vertical line for inflation rate is quarterly inflation rate in percent, $\left(\left(\frac{P_t}{P_{t+1}} \right)^4 - 1 \right) * 100$. The vertical for remittance is ratio of remittance to GDP in percent $\frac{H_t}{Y_t} * 100$. The blue line represents the outcomes in the consolidated model. The red line represents the outcomes in the unconsolidated model.

and Galí, 2007). Additionally, this exercise is motivated by the fact that, after such a shock, the central bank raises the nominal interest rate and incurs higher interest expenses.

Figure 2 shows the outcomes following a decline in productivity, A_t , by 5%. The blue line represents the outcomes in the consolidated model, while the red line represents the outcomes in the unconsolidated model. To simulate the dynamics, initial conditions for reserves and government bonds are provided. Reserves are set at a higher value, corresponding to the 90th percentile of the simulated economy, consistent with the previous exercise.

The intuition for the consolidated model is as follows: After a negative productivity shock, the government aims to reduce both labor supply and consumption. The marginal cost increases, leading to a rise in the inflation rate. To contract demand and lower inflation, the government raises the nominal interest rate. As aggregate output declines, tax revenue falls. In response, the government raises the tax rate and issues government bonds to smooth tax distortions over time.

For the central bank, with large initial reserves, it receives resources and continues to reduce reserves. Although the inflation rate rises only slightly (by 0.15%), this response is non-zero, which contrasts with the "divine coincidence," which suggests that under optimal policy, the inflation response should be zero. This discrepancy occurs because the government uses inflation to reduce real liabilities and relax the budget constraints of both the Treasury and the central bank. Importantly, the primary policy tool in response to a negative productivity shock is raising the nominal interest rate, which increases by 2.5 percentage points.

Next, I explain the intuition behind the unconsolidated model. A key result is that the central bank cannot raise the nominal interest rate sufficiently. The price of reserves does not decrease as much in the unconsolidated model compared to the consolidated model. This is because paying high interest on reserves leads to larger reserve balances, which cannot be reduced through remittances. When the shock hits, the central bank already holds large reserves, and by paying interest on these reserves, it issues more reserves. However, this does not satisfy the central bank's budget constraint due to the limited remittance. As a result, the government cannot raise the nominal interest rate enough.

Due to the lower nominal interest rate, consumption does not contract sufficiently in the unconsolidated model. Compared to the consolidated model, consumption responds 7% less in the unconsolidated model. Labor supply increases more in the unconsolidated model because house-

holds consume more. Additionally, the inflation rate is higher in the unconsolidated model because the interest rate cannot be raised enough to offset the inflationary shock.

On the fiscal side, the sales tax is lower in the unconsolidated model because firms need to produce more, and a lower sales tax leads to a higher marginal product. The Treasury also issues more government bonds because tax revenue is lower, but it still needs to finance public expenditure.

A natural question arises: why does the central bank issue large reserves by paying interest on reserves? The first reason is that large reserves do not satisfy the budget constraint when remittance is limited. Liabilities (reserves) must equal the present discounted value of assets and remittance. Since transfers from the Treasury are constrained, the issuance of reserves is also restricted. More interestingly, the second reason is that large reserves are needed to meet households' demand for reserves. To incentivize households to hold large reserves, the price of reserves must be low. However, this decline in the price of reserves affects real allocations through the households' Euler equation. This effect is costly, so the government does not want to issue excess reserves.

5.3 Public expenditure shock

This section describes the dynamics following a public expenditure shock. Motivated by the significant increase in public spending observed during the COVID-19 pandemic, I examine the role of the central bank in responding to a positive public expenditure shock. My results highlight how the central bank creates resources and supports the Treasury's budget through remittances. To demonstrate the central bank's capacity to generate resources, the initial condition assumes a large stock of government bonds, consistent with U.S. data, where the government liability-to-GDP ratio is 120%. The level of reserves is set at the steady-state, which differs from the exercises involving productivity and cost-push shocks.

Upon the shock, the Treasury holds a large amount of government bonds, limiting its capacity to issue additional bonds in response to the positive public expenditure shock. In contrast, the central bank holds reserves at their steady-state level, allowing it to create more resources by issuing additional reserves. While the marginal value of government bonds is low, the marginal value of reserves remains relatively high. This leads to a stark contrast between the consolidated and unconsolidated models.

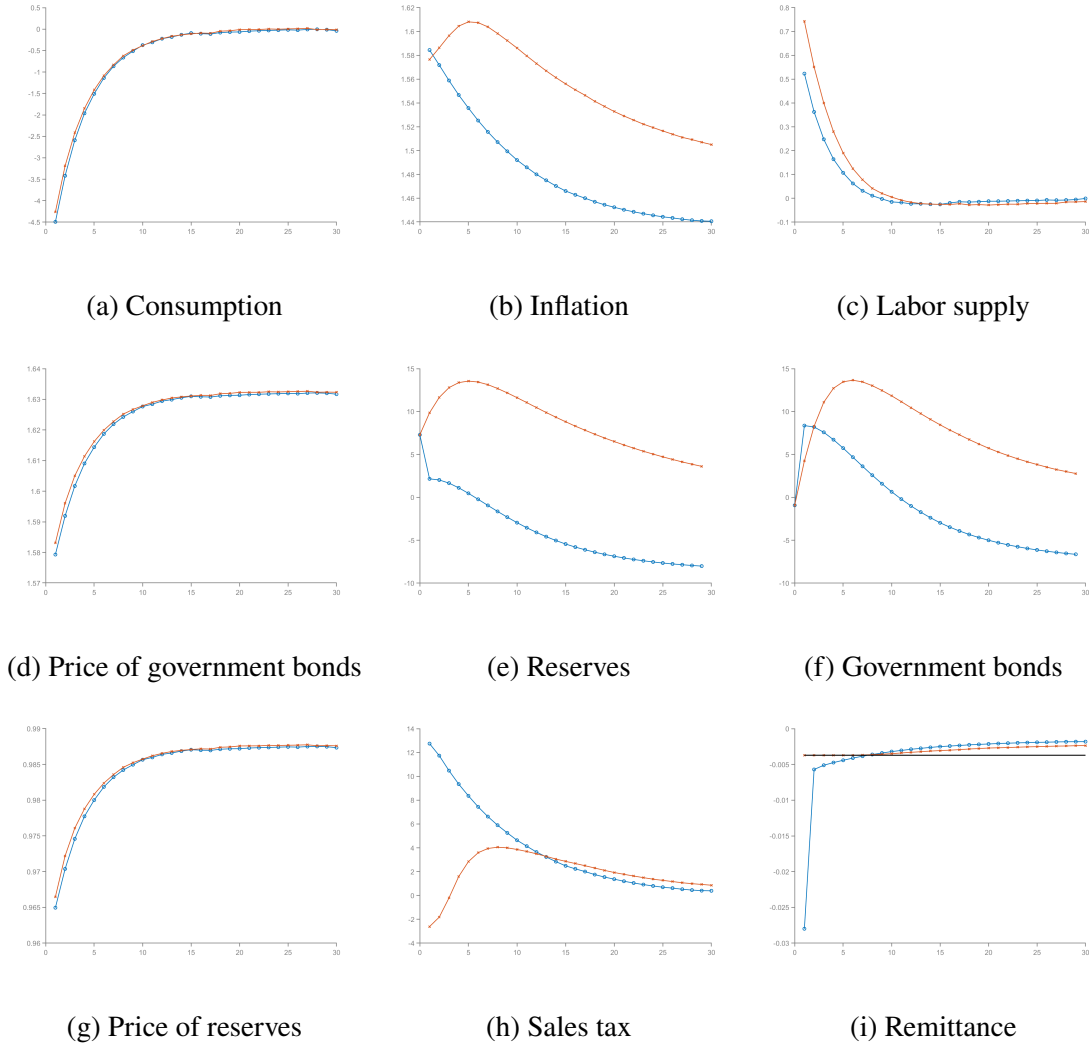


Figure 2: Productivity shock

Note: This figure shows the dynamics of key variables upon the negative productivity shock by 5%. The horizontal is quarters. The vertical lines for consumption, prices of reserves, prices of government bonds, reserves, government bonds are the steady-state deviation represented by percent. The vertical line for inflation rate is quarterly inflation rate in percent, $\left(\left(\frac{P_t}{P_{t+1}} \right)^4 - 1 \right) * 100$. The vertical for remittance is ratio of remittance to GDP in percent $\frac{H_t}{Y_t} * 100$. The blue line represents the outcomes in the consolidated model. The red line represents the outcomes in the unconsolidated model.

Figure 3 shows the outcomes following an increase in G_t by 3% of GDP. Public expenditure rises from 15% to 18% of GDP at time $t = 1$. The dynamics in the consolidated model are represented by the blue line, while the red line depicts the unconsolidated model. I will first explain the intuition behind the consolidated model.

The government experiences a positive public expenditure shock and responds by raising the tax rate, although this is distortionary. To smooth the tax distortion, the Treasury issues more bonds. Central bank issues more reserves. The central bank also transfers resources to support the Treasury's budget. Since the Treasury holds large government bonds at the time of the shock, their price declines to meet the increased demand for bonds. In contrast, reserves are relatively smaller in supply, so the price of reserves is lower than that of government bonds. The central bank uses these cheaper reserves to create additional resources, which are transferred to the Treasury. Upon the shock, remittances take a positive value, meaning that the Treasury receives resources from the central bank. Later, remittances fall below their steady-state level as the central bank receives transfers to reduce the increased reserves.

In terms of real allocations and inflation, labor supply increases to meet the demand for public expenditure, while consumption falls due to crowding out. The inflation rate rises as firms increase production, leading to higher marginal costs. Additionally, the government has an incentive to inflate nominal liabilities because the level of liabilities is higher. Regarding prices, the price of reserves is low and the nominal interest rate is high, which contracts consumption.

Next, I explain the intuition behind the unconsolidated model. In summary, the lack of fiscal backing for the central bank limits its ability to smooth taxes. In the unconsolidated model, remittances cannot fall below a certain threshold. While in the consolidated model, the central bank reduces reserves by receiving transfers from the Treasury, this is not feasible in the unconsolidated model. The central bank understands that large reserves cannot be reduced through remittances later, so it does not issue enough reserves. While the central bank increases reserves in the consolidated model, it does not do so sufficiently in the unconsolidated model. As a result, the central bank does not provide enough support to the Treasury by sending resources. This is shown in the path of remittance. In Figure 3-(h), at time $t = 1$, remittances take a higher value in the consolidated model, while they take a lower value in the unconsolidated model. This indicates that the central bank provides less support to the Treasury's budget in the unconsolidated model. Consequently, the

Treasury receives less help from the central bank and must issue more government bonds to finance the increased public expenditure. As a result, government bonds take on a higher value in the unconsolidated model. However, since the Treasury already holds a large quantity of government bonds and their price is high, it becomes difficult for the Treasury to issue enough bonds. This limits the government's ability to smooth taxes. Because the increase in public expenditure is not smoothed through the issuance of liabilities, the higher public expenditure is financed through taxes, resulting in a greater tax rate response in the unconsolidated model compared to the consolidated model.

In terms of real allocations, a higher tax rate on sales leads to lower production, i.e., lower labor supply. The difference in consumption between the two models is not significant. However, the inflation rate remains persistently higher in the unconsolidated model as a way to reduce reserves by inflating nominal liabilities, that is, inflating reserves.

Note that these results critically depend on the assumption that the Treasury holds a large amount of government bonds at the time of the shock. Large government bonds limit the Treasury's ability to smooth taxes, making fiscal support from the central bank more crucial when responding to a public expenditure shock. Why is this important? The difference between the unconsolidated model and consolidated model is essentially central bank's ability to fiscally support Treasury. The lack of fiscal backing for the central bank restricts the central bank's ability to provide this support. Since fiscal support from the central bank becomes even more important when the Treasury holds a significant amount of government bonds, the difference between the unconsolidated and consolidated models becomes stark. To show the importance of initial condition, Appendix B.1 shows the dynamics when the economy starts from steady-state reserves and government bonds. It shows that the difference between the two models is smaller than that when initial government bonds are small.

6 Dynamic properties of the policies and allocations

This section is motivated by the question of optimal monetary and fiscal policy over the business cycle. The literature on optimal monetary and fiscal policy addresses how these policies should be set during the business cycle, with particular focus on two questions: (i) the optimal volatility of

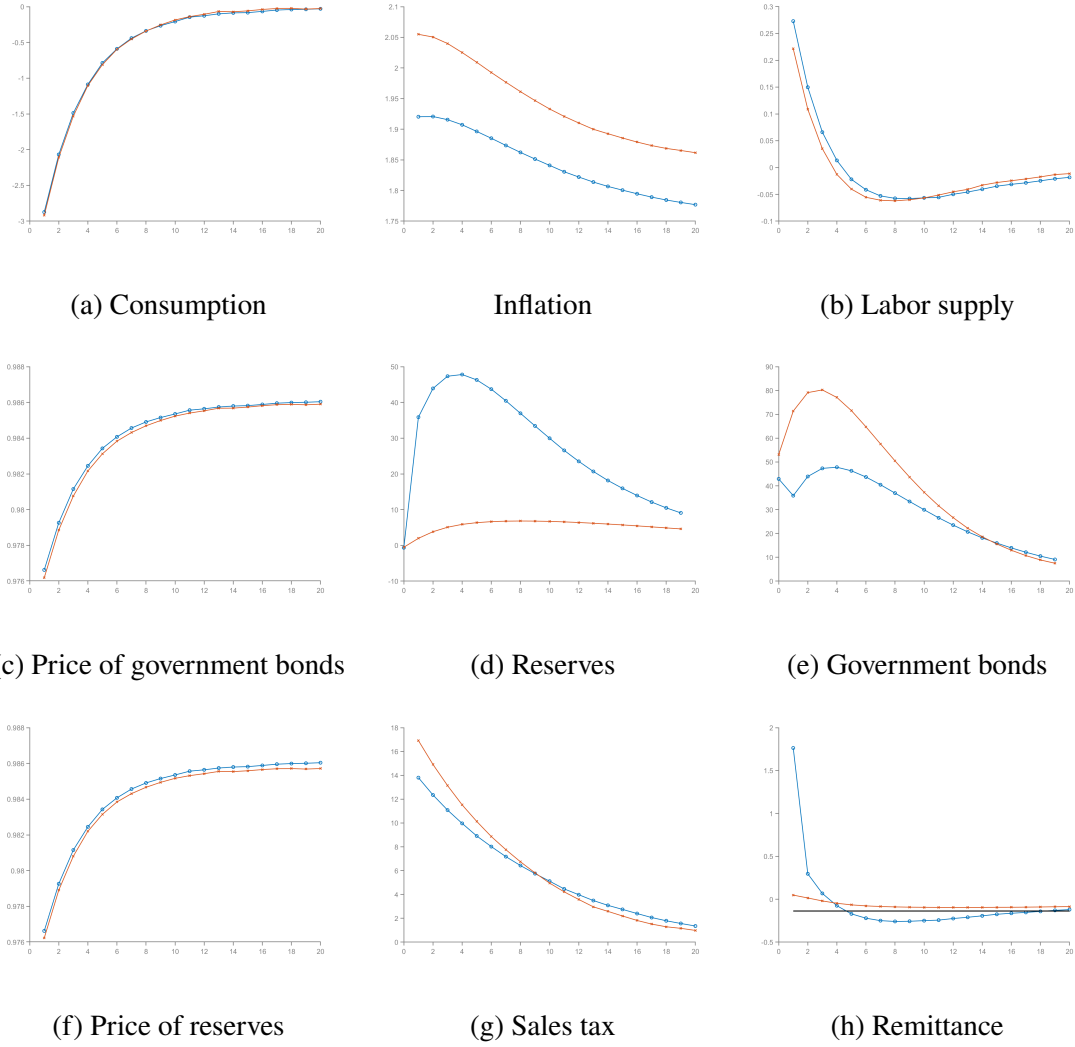


Figure 3: Public expenditure shock

Note: This figure shows the dynamics of key variables upon the positive shock by 3%. The horizontal is quarters. The vertical lines for consumption, prices of reserves, prices of government bonds, reserves, government bonds are the steady-state deviation represented by percent. The vertical line for inflation rate is quarterly inflation rate in percent, $\left(\left(\frac{P_t}{P_{t+1}} \right)^4 - 1 \right) * 100$. The vertical for remittance is ratio of remittance to GDP in percent $\frac{H_t}{Y_t} * 100$. The blue line represents the outcomes in the consolidated model. The red line represents the outcomes in the unconsolidated model.

inflation: how does the government use inflation to stabilize nominal debt? and (ii) the persistence of taxes and debt: how does the government smooth tax distortions by issuing liabilities? This paper addresses these questions while sharing key elements with earlier literature, including: (a) taxes are distortionary, (b) the government issues only nominal and non-state-contingent debt, and (c) product prices are sticky. A key deviation from previous studies is the constraint on transfers from the Treasury to the central bank.

This section presents several sample moments for key macroeconomic variables, as well as monetary and fiscal policy variables, liabilities, and remittances under both the unconsolidated and consolidated models. The goal is to compare the moments between the two models. The moments of interest include the volatility of inflation and tax rates, as well as the persistence of reserves and government bonds.

The moments are computed as follows: I first generate simulated time series of length T for the variables and calculate the corresponding moments. This procedure is repeated J times, and the average of the moments is computed. In the table, T equals 1000 periods, and J equals 1000 repetitions. The economy is simulated with one shock, while other shocks are excluded due to the large size of the state-space.

6.1 Dynamic property of monetary-fiscal policy and consumption

Table 2 presents the moments for inflation, consumption, and the tax rate in both the consolidated and unconsolidated models. Each panel displays the moments for each shock. Given the size of the state-space, I simulate the model with one shock at a time, excluding the others. The optimal policy is under discretion rather than commitment, as studied in Chari, Christiano, and Kehoe (1991); Schmitt-Grohé and Uribe (2004), which makes direct numerical comparisons with the literature challenging. The volatility of the inflation rate is generally low for all shocks, reflecting the application of optimal monetary and fiscal policy.

The main results are as follows: (i) inflation is more volatile in the unconsolidated model across all shocks; (ii) the average inflation rate increases, though the rise is small; (iii) while the tax rate is more volatile in response to productivity and government expenditure shocks in the unconsolidated model, it is less volatile for cost-push shocks; and (iv) the volatility of consumption is minimally

affected.

First, I provide the intuition for the cost-push shock. In the consolidated model, the volatility of inflation and consumption is caused by the cost-push shock, which affects marginal costs. A positive cost-push shock raises inflation and reduces consumption. The volatility of the tax rate arises because the government seeks to align marginal cost with marginal product. When marginal costs rise, it becomes optimal to lower the sales tax rate, as a lower tax rate increases the marginal product. This mechanism is evident in the correlations with the shock: inflation is positively correlated, while consumption and the tax rate are negatively correlated with the shock.

In the unconsolidated model, inflation is more volatile, and the tax rate is less volatile compared to the consolidated model. This is because the issuance of reserves is constrained—large reserves cannot be reduced through remittances. As a result, the central bank does not issue enough reserves and cannot provide sufficient support to the Treasury. The limited ability to reduce taxes in response to the cost-push shock reduces the volatility of the tax rate in the unconsolidated model. Consequently, inflation volatility is higher because changes in the sales tax rate do not sufficiently offset the cost-push shock.

Let me explain the intuition for the consolidated model in response to a public expenditure shock. When a public expenditure shock occurs, the government raises tax rates to finance the increased expenditure. However, since taxes are distortionary, the government smoothes this adjustment over time. This is evident in the high positive correlation between taxes and the public expenditure shock, as well as the high autocorrelation of the tax rate. Consumption is crowded out following a public expenditure shock, and the government increases the inflation rate to reduce the real value of debt, as debt levels rise after the shock. This is reflected in the negative correlation between consumption and the shock, and the positive correlation between inflation and the shock. The volatility of the inflation rate arises from the government's efforts to reduce the real value of debt, while the volatility of the tax rate stems from tax smoothing.

Although the government uses inflation to reduce the real value of debt, this motive is quantitatively small because inflation is costly. In the consolidated model, the volatility of inflation is low, with a standard deviation of less than 0.1 percentage points. While the government has an incentive to use inflation to lower nominal liabilities, the cost of inflation due to price stickiness outweighs the benefits. Schmitt-Grohé and Uribe (2004) find similar results under a Ramsey equilibrium, and

while my model operates under discretion, the findings are consistent.

In the unconsolidated model, the volatility of inflation, consumption, and the tax rate is higher than in the consolidated model. The key issue is the government's tax smoothing motive. When faced with a public expenditure shock, the government seeks to smooth tax distortions over time by issuing liabilities. The central bank can issue reserves to support the Treasury's budget by providing resources. However, in the unconsolidated model, the issuance of reserves is constrained, limiting the government's ability to smooth taxes. The volatility of the sales tax leads to volatility in output and inflation through firms' first-order conditions. In summary, the lack of fiscal backing in the unconsolidated model restricts the government's ability to smooth taxes.

6.2 Persistency of liabilities and taxes

An important result in the public finance literature is the idea of smoothing tax distortions over time. Lucas and Stokey (1983) show that government bonds inherit the stochastic process of exogenous shocks. This implies that if shocks are serially uncorrelated, government bonds should also follow an uncorrelated process. However, Barro (1979) and Aiyagari et al. (2002) demonstrate that Lucas and Stokey's results depend on the assumption that the government can issue state-contingent debt. They show that, in the absence of state-contingent debt, government bonds follow a near random walk behavior, regardless of the process assumed for the shocks. This paper examines the process of liabilities and taxes in a setting with non-state-contingent nominal debt and sticky prices, similar to Schmitt-Grohé and Uribe (2004).

The consolidated model in this paper is a standard New Keynesian framework, similar to Schmitt-Grohé and Uribe (2004). The key deviation from the literature is the inclusion of reserves. In the data, reserves are significantly large, making it interesting to study their behavior. The purpose of this section is to investigate whether both reserves and government bonds follow a near random walk under discretion. Additionally, this paper explores the implications of the lack of fiscal support: does the absence of fiscal backing change the stochastic behavior of reserves and government bonds? Moreover, does it alter the properties of taxation?

Table 3 presents the moments for reserves, government bonds, and tax rates. In the consolidated model, both reserves and government bonds exhibit persistent behavior across all types of shocks,

Table 2: Dybamic properties of the optimal policy

Variable	Mean	Std. dev.	Auto. corr.	Corr w. shock
<i>Consolidated model with cost-push shock</i>				
π	1.741	0.0862	0.93	0.81
c_t	88.5	0.14	0.84	-0.94
τ_t	10.2	0.52	0.57	-0.78
<i>Unconsolidated model with cost-push shock</i>				
π	1.803	0.0898	0.90	0.82
C_t	88.5	0.00	0.79	-0.96
τ_t	10.3	0.43	0.49	-0.80
<i>Consolidated model with productivity shock</i>				
π	1.759	0.0120	0.93	-0.84
c_t	88.5	0.010	0.73	1.00
τ_t	10.2	0.094	0.90	-0.89
<i>Unconsolidated model with productivity shock</i>				
π	1.767	0.0130	0.91	-0.85
c_t	88.5	0.010	0.74	1.00
τ_t	10.3	0.097	0.87	-0.94
<i>Consolidated model with public expenditure shock</i>				
π	1.765	0.0615	0.93	0.80
c_t	88.5	0.643	0.72	-1.00
τ_t	10.3	0.473	0.88	0.88
<i>Unconsolidated model with public expenditure shock</i>				
π	1.839	0.0791	0.93	0.76
c_t	88.5	0.647	0.71	-1.00
τ_t	10.3	0.482	0.86	0.91

Notes: π, τ are expressed in percentage points, and c are in levels.

consistent with the findings of Schmitt-Grohé and Uribe (2004). The autocorrelations of reserves and government bonds are close to one, indicating their highly persistent nature.

Both reserves and government bonds show near random walk property. Government uses both to smooth tax. Households get convenience yield from reserves and government bonds that are imperfect substitute. If government uses only one of reserves or government bonds to smooth tax, marginal utility of that liability is higher than the other and this is not optimal.

For taxes, while the autocorrelation is high for productivity and public expenditure shocks, it is lower for cost-push shocks. This difference reflects the government's tax-smoothing motive for productivity and public expenditure shocks, where taxes are adjusted over time. For cost-push shocks, however, the government adjusts sales taxes to offset the shock's impact on marginal costs, which leads to a lower autocorrelation.

In the case of a public expenditure shock, taxes are used primarily to finance the increase in public spending. For a productivity shock, taxes are adjusted to compensate for changes in tax revenue due to fluctuations in output. In both cases, the government uses taxes to finance public expenditures, resulting in a strong tax-smoothing motive. In contrast, during a cost-push shock, sales taxes are adjusted to influence marginal costs in response to the shock, leading to a tax process that closely follows the process of the shock, thus explaining the lower autocorrelation.

In the unconsolidated model, the lack of fiscal support causes reserves to become more persistent and government bonds less persistent across all types of shocks. For reserves, the mechanism is similar for all shocks: once the central bank issues reserves, the ability to reduce them through remittance is limited. As a result, reserves decrease slowly, leading to higher persistence.

For government bonds, the persistence is lower in the unconsolidated model. This occurs because the response of government bonds to shocks is larger in the unconsolidated model than in the consolidated model. After this larger response, government bonds return to their steady-state, making them more volatile and less persistent. Why is the response of government bonds larger?

In the consolidated model, the increased demand for liabilities is distributed between reserves and government bonds, as the government utilizes both to generate resources. However, in the unconsolidated model, the central bank's ability to use reserves for tax smoothing is constrained. As a result, the government relies more heavily on government bonds to create resources, making bonds more responsive to shocks and more volatile. Consequently, government bonds exhibit less

Table 3: Autocorrelation of reserves, government bonds, and tax

Reserves	Government bonds	Tax on sales
<i>Consolidated model with cost-push shock</i>		
0.97	0.97	0.57
<i>Unconsolidated model with cost-push shock</i>		
0.99	0.96	0.49
<i>Consolidated model with productivity shock</i>		
0.98	0.98	0.90
<i>Unconsolidated model with productivity shock</i>		
0.99	0.94	0.87
<i>Consolidated model with public expenditure shock</i>		
0.97	0.97	0.88
<i>Unconsolidated model with public expenditure shock</i>		
0.99	0.96	0.86

Notes: Reserves, government bonds, and tax rate are in levels.

persistence in the unconsolidated model.

6.3 Implications on retained earnings

This section discusses the relationship between the model and the actual policies of central banks. A key feature of my model is the transfers between the central bank and the Treasury, which naturally raises the question of how central banks decide on their remittances in practice. An important observation is that many central banks retain part of their earnings and do not transfer the entire profit to the Treasury.

In the UK, the remittance policy depends on the central bank's net worth. If the Bank of England's net worth is below a target level, all profits are retained to boost net worth. If net worth is above the target but below a ceiling level, half of the profits go to the Treasury, while the other

half is added to capital. If net worth exceeds the ceiling, all profits are transferred to the Treasury.⁶ In Japan, 5% of the Bank of Japan's profits are retained, with the remaining 95% transferred to the Treasury. In summary, many central banks retain a portion of their profits and do not transfer the entire amount to the Treasury. The Federal Reserve, however, is an exception. In the U.S., the Federal Reserve Act requires the Reserve Banks to remit excess earnings to the U.S. Treasury after covering operating costs. This implies that, during periods when profits exceed costs, remittances are equal to profits, and the Federal Reserve does not accumulate its net worth.

Can the unconsolidated model replicate the fact that central banks do not transfer their entire profit? Is the unconsolidated model more consistent with actual practice than the consolidated model? The answer is yes: the unconsolidated model is more consistent with real-world central bank policies.

Figure 4 presents a histogram of remittances over the business cycle in both the consolidated and unconsolidated models. I simulate the economy for 1000 periods and generate a sequence of remittances for both models. The histograms display remittances in the consolidated model (blue) and the unconsolidated model (red). The left side shows cases where the central bank receives transfers, while the right side shows cases where the Treasury receives remittances.

In the unconsolidated model, there is a lower bound on remittances, meaning the central bank cannot receive more than a certain threshold. Notably, remittances take on higher values less frequently in the unconsolidated model compared to the consolidated model, particularly at the right tail of the histogram. While the unconsolidated model imposes a lower bound on remittances, this constraint also affects the upper tail of the remittance distribution, making it thinner. Intuitively, if the central bank prints more reserves and transfers more to the Treasury, the excess reserves cannot be reduced through remittances due to the constraint. As a result, the central bank chooses not to transfer more. This behavior aligns with the actual practice of central banks, where remittances are often lower due to retained earnings.

⁶See here for details on the BoE's remittance policy.

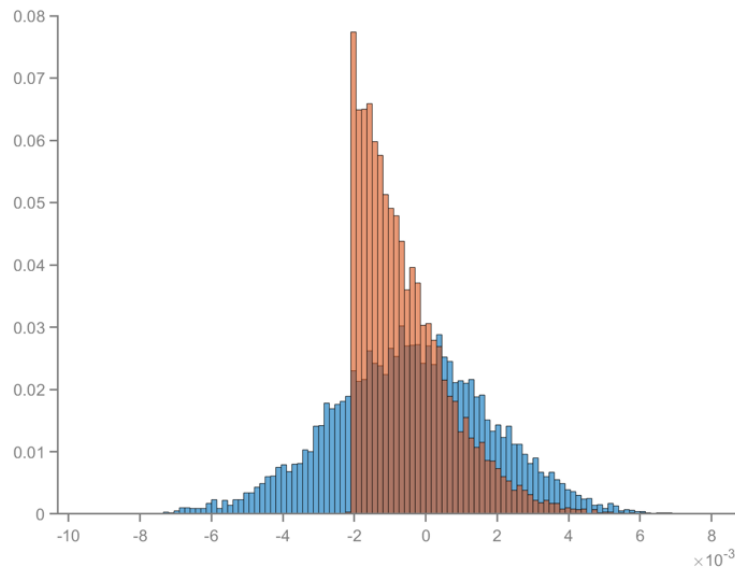


Figure 4: The histogram of remittance in the consolidated and unconsolidated model.

Note: This figure shows a histogram remittance in the consolidated and unconsolidated model. I simulate an economy for 1000 periods and obtain a sequence of remittance for both models. An underlying exogenous shock is cost-push shock. I show it as a histogram after normalization so that an area is equal to one.

7 Welfare analysis

This section discusses the welfare gain of fiscal backing. I compare the welfare loss because of cost-push shock in the unconsolidated model and the consolidated model. The following is a procedure. First, a positive cost-push shock reduces the utility of household. I compute the perpetual consumption transfer necessary to make the household utility after cost-push shock as well off as the households that are always in steady-state. For example, if a cost-push shock is zero, I obtain zero. If a cost-push shock is a 2% increase, household worse off by 0.02% of consumption. For each size of cost-push shock, I compute the welfare cost of the shock. Second, I do the same exercise for both models.

Figure 5 shows the results. The horizontal axis is the size of shock represented by percentage point. The vertical axis is the welfare cost of cost-push shock represented by consumption equivalence in percentage point. The red is the welfare cost in the unconsolidated mode. The blue is that in consolidated model. First, the welfare cost of cost-push shock is larger in unconsolidated model than in consolidated model. Second, the difference gets larger as the size of shock increases. For example, when cost-push shock is 9% increase, the welfare cost is 0.11% of consumption in the uncluttered model and 0.9% in the consolidated model.

The welfare loss in the unconsolidated model comes from insufficient tax break because of the lack of fiscal backing. Treasury wants to do tax break upon the cost-push shock, and central bank helps Treasury by sending resources to Treasury. This is limited in the unconsolidated model, so tax break is insufficient. Cost-push shock that is not offset by tax break lowers consumption and inflation rate is high, that is costly in terms of welfare.

8 Conclusion

This paper studies optimal monetary and fiscal policy when Treasury is unable to provide optimal fiscal support to the central bank. The central bank holds large reserves and incurs interest expenses. During periods when costs exceed earnings, the Federal Reserve does not receive transfers from Treasury to offset the losses. I analyze the optimal monetary and fiscal policy in a New-Keynesian model with central bank and Treasury, where the transfer of resources from Treasury to the central

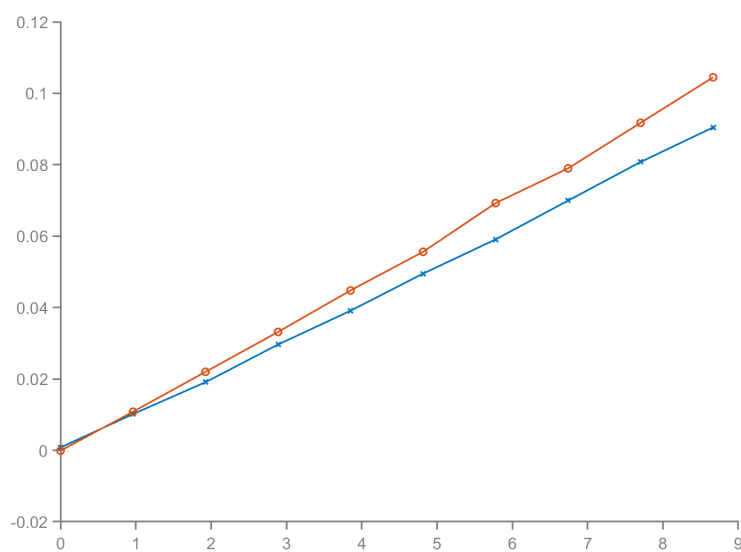


Figure 5: The welfare gain of fiscal backing and size of shock.

Note: This figure shows The welfare gain of fiscal backing and size of shock. The horizontal axis is the size of shock represented by percentage point. The vertical axis is the welfare cost of cost-push shock represented by consumption equivalence in percentage point. The red is the welfare cost in the unconsolidated mode. The blue is that in consolidated model.

bank is constrained, but not vice versa. This lack of fiscal support implies: (i) the central bank, without fiscal backing, tolerates higher inflation in response to cost-push shocks, and this inflation response increases with the level of reserves; (ii) while the lack of fiscal support increases the volatility of the optimal inflation rate by 3%, the average optimal inflation rate is minimally affected; (iii) the welfare gains from fiscal support are small over the business cycle, but in the case of large shocks, a fiscal backstop reduces the welfare cost of the shock by 20%.

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Appendix A Details on calibration

This section describes details on calibration. key parameters are γ_1 and γ_2 that deciplines the curvature of utility in convenience yield term.

In the Euler equation for reserves, a price of reserves (Q^C in the left hand side) depends on the quantity of reserves (d_t in the right hand side).

$$\text{(Euler for reserve)} \quad C_t^{-\sigma} Q_t^C = \beta E_t \left[\frac{C_{t+1}^{-\sigma}}{\pi_{t+1}} \right] + \chi_1 (Q_t^C d_t)^{-\gamma_1} Q_t^C \quad (47)$$

When I take the left-hand side derivative with respect to d_t , this derivative depends on γ_1 . That suggests that the elasticity of price to quantity is deciplined by γ_1 . High γ_1 means that the elasticity is higher i.e, the slope of the demand curve is steep. Low γ_1 means that the elasticity is lower i.e, the slope of the demand curve is flat. Although this is not mathematically very precise, I confirmed that in equilibrium, the elasticity of price to quantitiy decreases with γ_1 .

The purpose of this calibration is to match the price elasticity in data to that in model. I run regression both in model and data.

In the model, I simulate the economy and obtain the sequence of the left-hand side and $\frac{b_t^C}{Y_t}$ in equation (49) and $\frac{b_t^T}{Y_t}$ in equation (53). Then, I obtain estimated β_1 and β_3 by running time-series regression of (49) and (53). The β_1 and β_3 are negative and decreases with γ_1 and γ_2 .

In data, I also estimate equations (51) and (54). For reserves, I control deposits following Vissing-Jorgensen (2023). For government bonds, I follow Krishnamurthy and Vissing-Jorgensen (2012). I use data from 2009 to 2020. The frequency of data is quarterly. EFR represents the effective fed fund rate. IOR represents interest rate on reserves. Reserves are 'Reserve Balances with Federal Reserve Banks' in FRED. All data is available on FRED.

For reserves and γ_1

$$\text{model} \quad r_t - i_t = \beta_0 + \beta_1 \log\left(\frac{d_t}{Y_t}\right) + \epsilon_t \quad (48)$$

$$r_t \equiv \beta E_t \left[\frac{C_{t+1}^{-\sigma}}{\pi_{t+1}} \right] \frac{1}{C_t^{-\sigma}} \quad (49)$$

$$i_t \equiv \frac{1}{Q_t^d}. \quad (50)$$

$$\text{data} \quad \text{EFR}_t - \text{IOR}_t = \tilde{\beta}_0 + \tilde{\beta}_1 \log\left(\frac{\text{Reserve}_t}{\text{GDP}_t}\right) + \log(\text{Deposit}_t) + \epsilon_t. \quad (51)$$

I proxy the effective fed fund rate in data as r_t that is the hypothetical nominal interest rate obtained if there is no convenience value for reserves. i_t in the model is the price of reserves when there is a convenience yielded for reserves.

For γ_2 and government bonds. For Treasury yield, I use yield of 1 month, 3 month, and 6 month maturity's government bonds. Both Treasury yield and effective federal funds rate are annualized. Federal liability is Federal government's liability in FRED.

$$\text{model} \quad r_t - i_t^T = \beta_2 + \beta_3 \log\left(\frac{b_t}{Y_t}\right) + \epsilon_t \quad (52)$$

$$i_t^T \equiv \frac{1}{Q_t^b}. \quad (53)$$

$$\text{data} \quad \text{EFR}_t - \text{Treasury yield}_t = \tilde{\beta}_2 + \tilde{\beta}_3 \log\left(\frac{\text{Federal liability}_t}{\text{GDP}_t}\right) + \epsilon_t. \quad (54)$$

Table 4 and 5 show estimated results. In data, the estimated $\tilde{\beta}_1$ are significantly negative, that is a demand curve is downward-sloping. I target $\tilde{\beta}_1 = -0.2$. For government bonds, I target $\tilde{\beta}_3 = -0.1$. I choose γ_1 and γ_2 so that I have $\tilde{\beta}_1 = -0.2$. and $\tilde{\beta}_3 = -0.1$.

Appendix B Dynamics from steady-state level of reserves and government bonds

B.1 Public expenditure

This section describes the dynamics after a positive public expenditure shock. The initial condition for reserves and government bonds are steady-state level, unlike the exercise in section 5.3 where the economy starts from large government bonds. The goal of this section is to show the difference between the unconsolidated and consolidated model depends on the initial conditions.

Figure 6 shows results. The key different from figure 6 and figure 3 is sales tax. In figure 6, the unconsolidated model shows that tax smoothing is limited; the initial response of tax rate in the unconsolidated model is larger than that in the consolidated model. However, the overshooting of tax rate in the unconsolidated model is smaller in figure 6 than that in 3. This is because Treasury holds relatively smaller government bonds in exercise of 6. Treasury has more capacity to issue government bonds more, and can smooth tax even though support from central bank is limited.

Table 4

<i>Dependent variable:</i>		
	$\text{EFR}_t - \text{IOR}_t$	
	(1)	(2)
$\log(\text{res_gdp})$	-0.165^{***} (0.026)	-0.297^{***} (0.024)
$\log(\text{dep_gdp})$		0.020^{***} (0.003)
Constant	0.297^{***} (0.062)	0.667^{***} (0.064)
Observations	36	36
R^2	0.545	0.827

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5

	<i>Dependent variable:</i>		
	$\text{EFR}_t - 1 \text{ month}_t$	$\text{EFR}_t - 3 \text{ month}_t$	$\text{EFR}_t - 6 \text{ month}_t$
	(1)	(2)	(3)
$\log(\text{debt_gdp})$	0.057 (0.102)	-0.105 (0.136)	-0.321 (0.220)
Constant	-0.178 (0.447)	0.495 (0.596)	1.361 (0.963)
Observations	40	40	40
R^2	0.008	0.015	0.053

Notes: "1 month", "3 month", and "6 month" represents the yield of each maturities Treasury bonds. * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

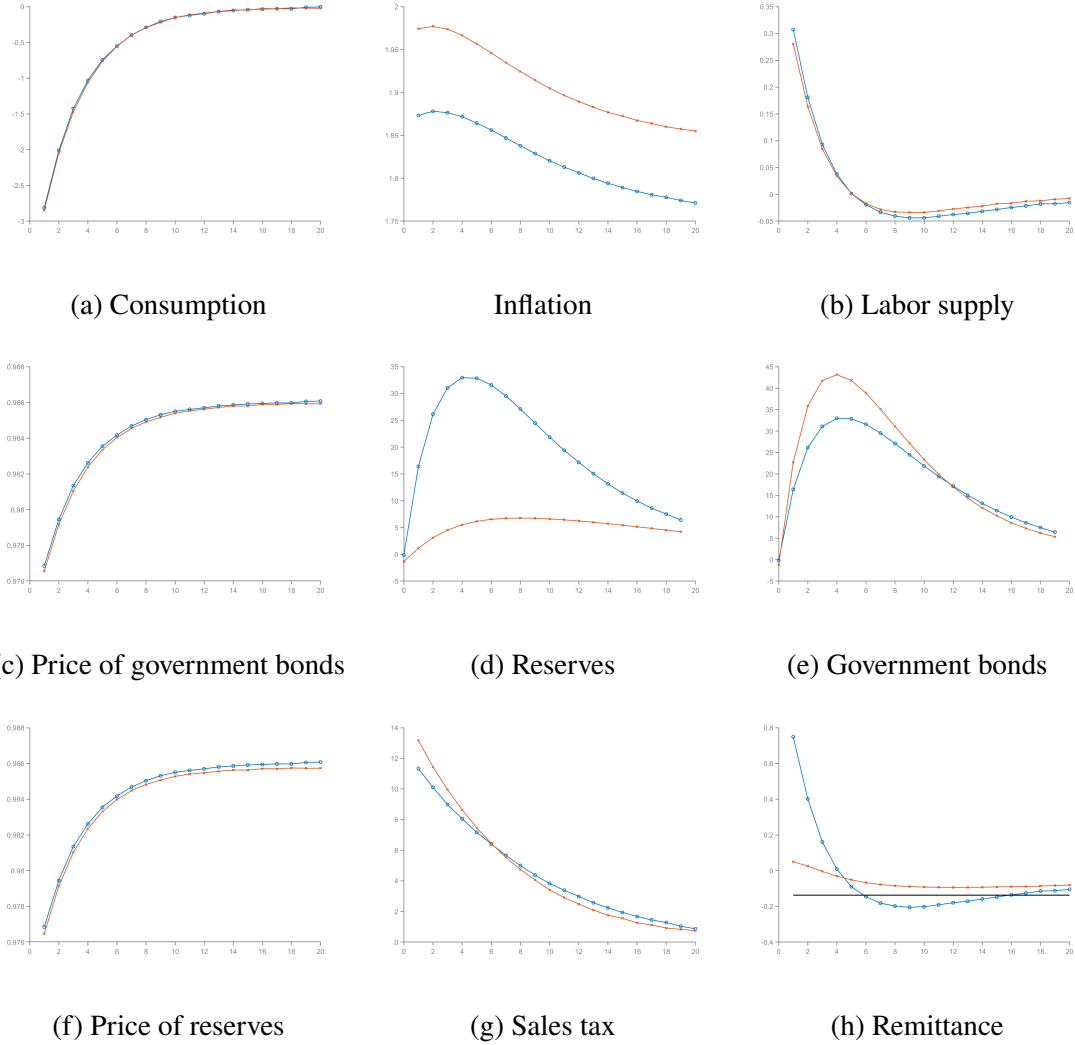


Figure 6: Public expenditure shock

Note: This figure shows the dynamics of key variables upon the positive shock by 3%. The horizontal is quarters. The vertical lines for consumption, prices of reserves, prices of government bonds, reserves, government bonds are the steady-state deviation represented by percent. The vertical line for inflation rate is quarterly inflation rate in percent, $\left(\left(\frac{P_t}{P_{t+1}} \right)^4 - 1 \right) * 100$. The vertical for remittance is ratio of remittance to GDP in percent $\frac{H_t}{Y_t} * 100$. The blue line represents the outcomes in the consolidated model. The red line represents the outcomes in the unconsolidated model.