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Fiscal Consolidation and Public Wages

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Abstract

A New Keynesian model with government production, public compensation, and unemployment is fit to U.S. data to study the macroeconomic and fiscal effects of public wage reductions. We find that accounting for the type of government spending is crucial for its macroeconomic implications. Although reductions in public wages and government purchases of goods have similar effects on total output and the fiscal balance, the former can raise private output slightly, in contrast to the substantial contractionary effects of the latter. In addition, the baseline estimation finds that exogenous public wage reductions decrease private wages. Model counterfactuals show that sufficiently rigid nominal private wages can reverse the response of private wages, as the rigidity dampens the labor reallocation effect from the public to private sector that exerts downward pressure on private wages.

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1. Introduction

Following the global financial crisis, many governments restrained public wage growth in an effort to stabilize public debt. Of the 30 participating countries in the Fiscal Consolidation Survey (OECD (2011)), 20 reported reducing public-sector wages. Comparing the five-year periods before and after the crisis, Forni and Novta (2014) find that the number of episodes of public wage reductions increased dramatically from 3 during 2003-2007 to 25 during 2009-2013 among OECD and some eastern European countries. In the U.S., following the debt build-up at the onset of the Great Recession, total government compensation as a share of GDP declined for all government levels (see Figure 1). Moreover, public wage reductions were a key source of the recent decline in the U.S. government compensation-to-GDP share. Some argue the prolonged reductions in public wages, particularly by S&L governments, extended the slow recovery from the Great Recession (e.g., Morrissey (2014), Bivens (2016), and Fernald et al. (2017)).

Traditionally, the literature on government spending effects focuses on goods purchases. In light of the increasing importance of government compensation, several recent studies have examined its macroeconomic implications (e.g., Quadrini and Trigari (2007), Afonso and Gomes (2014), Gomes (2015), Pérez et al. (2016), Bermperoglou et al. (2017), Bradley et al. (2017), and Bandeira et al. (2018)).[1] Relative to these works, we estimate with Bayesian inference methods a New Keynesian model that includes both public compensation and government purchases of goods, an exercise heretofore not pursued in the literature. Estimation disciplines the model to U.S. data, allowing us to quantify which transmission channels following a public wage shock are favored by the data. Moreover, estimation allows a quantitative assessment of the relative contribution of public wage shocks in accounting for the recent dynamics of fiscal and macroeconomic variables.

[1]In addition to recent studies, several earlier papers study government employment effects, such as Finn (1998), Forni et al. (2009), Linnemann (2009), and Pappa (2009). These papers do not distinguish between public and private wages and hence cannot be used to examine public wage effects.

Our framework builds on a standard, estimated New Keynesian model with nominal price and wage rigidities and fiscal policy (see for instance, Traum and Yang (2011) and Zubairy (2014) with U.S. data). We add a public production sector to capture the value added of public services and to disentangle the effects of public wage changes on private versus aggregate output. Given that public and private labor may be imperfect substitutes, we introduce sectoral wage differences and allow for and estimate a labor mobility friction.[2] As public wage policy has been shown to be important in explaining business-cycle fluctuations in unemployment (Gomes (2015)), we also incorporate the theory of unemployment proposed in Gal'i (2011) and Galí et al. (2012). The model is estimated with S&L fiscal data, since 1) over 70% of U.S. public compensation is at the S&L level over our sample and 2) S&L government compensation as a share of GDP contracted more than federal compensation after the Great Recession (see Figure 1).[3]

We find that accounting for the type of government spending is crucial for its macroeconomic implications. In particular, a public wage reduction can be expansionary for private output, while a goods purchase reduction is contractionary. Although the two types of spending have quantitatively similar short-run multipliers for *total* output, the multipliers for *private* output have the opposite signs: the mean impact multiplier is -0.03 for public wages and 0.97 for goods purchases. The expansion in private output following a decrease in public wages mainly is driven by an increase in the after-tax return to investment, as lower public debt requires less future taxation.

In addition, we find that an exogenous public wage reduction pushes down real private wages in the short run. Our model has two main channels for an exogenous public wage change to affect private wage dynamics. The first channel works through labor reallocation.

[2]The premium of public-sector wages relative to private-sector wages is widely documented in the literature, e.g., Falk (2012) for the U.S., de Castro et al. (2013) for European Union countries, and Hospido and Moral-Benito (2016) for Spain.

[3]Bermperoglou et al. (2017) suggest the importance in considering the level of government data, as they find public wage shocks have distinct effects for different government levels using a structural VAR. In addition, federal and S&L governments have very different reactions to debt accumulation, as S&L governments are constrained by balanced-budget requirements.

A public-wage reduction induces some labor to reallocate from the public to the private sector, which exerts downward pressure on real private wages. The strength of this channel depends on the degree of labor mobility friction—which can prevent labor reallocation directly—and nominal wage rigidities—which prevent wage adjustments. The second channel works through goods demand. Lower government compensation (or lower government spending in general) induces a positive wealth effect, driving down the real interest rate. With a reduced public wage rate, private consumption has little response as households receive less income from working in the public sector, which offsets the positive wealth effect. Investment, however, increases in response to a lower real interest rate. Overall, a public wage reduction boosts demand for goods and hence for private-sector labor, which exerts upward pressure on real private wages. Since the two channels move private wages in the opposite directions, the response of real private wages depends on their relative strength. Under our baseline estimation, the labor reallocation effect dominates: real private wages fall in response to a public wage reduction. When nominal private wages are more rigid, sensitivity analysis shows that private wages can rise in the short run following a negative public wage shock.

Finally, historical decompositions show that public wage reductions worked effectively to increase the primary fiscal balance of S&L governments after 2008. Moreover, consolidations by S&L governments, either via public wage reductions or other fiscal measures, only played a minor role for total output dynamics. This suggests that S&L governments' consolidation measures were not a major cause of the slow recovery from the Great Recession.

Our paper is closely related to a few recent theoretical studies on the macroeconomic effects of public wage changes. Bandeira et al. (2018) identify the two effects—goods demand and labor reallocation effects—as drivers of the private wage dynamics following a public wage consolidation in a monetary union. Relative to their framework, we incorporate a nominal wage rigidity that we show is central for the interaction of the two effects in the private wage response to a public wage shock.[4] Bermperoglou et al. (2017) show that complementarity between private consumption and public services can influence whether public wages are expansionary or contractionary. In addition, Ardagna (2007), Pappa (2009), and Bandeira et al. (2018) show that the results are dependent on whether public services enter the private production function. Taking advantage of our Bayesian approach, we perform model comparisons to evaluate the relative quantitative performance of these alternative channels through utility-enhancing public services and productive public services. Model comparisons show that our baseline specification is favored by the data relative to the frameworks with either utility-enhancing services or productive public services.

The rest of the paper is organized as follows. Sections 2 and 3 outline the model and estimation details, respectively. Section 4 discusses the macroeconomic effects of exogenous public wage reductions. Section 5 studies the robustness of our results to several alternative specifications. Section 6 concludes.

2. The Baseline Model

We modify a standard New Keynesian model with fiscal policy (à la e.g., Smets and Wouters (2003, 2007), Christiano et al. (2005), and Traum and Yang (2011)) to include unemployment (as in Gal'i (2011) and Galí et al. (2012)), public production, a labor mobility friction between public and private sectors, and differences in the determination of public and private wages.

2.1. **Firms.** The private production sector consists of intermediate and final goods producing firms. A perfectly competitive final goods producer uses a continuum of intermediate

[4]Although nominal wage rigidities have not been taken into account when studying public compensation, wage rigidities are empirically relevant in the quantitative general-equilibrium and labor search literatures. Krause and Lubik (2007) and Gertler and Trigari (2009) show that a reasonably calibrated labor search model with sticky nominal wages can account for the cyclical wages and labor dynamics in the data. Gertler et al. (2008) show that wages are just as sticky and the transmission mechanisms are just as those in the seminal NK models, as in Smets and Wouters (2003, 2007).

inputs $Y_{i,t}^P$, where $i \in [0,1]$, to produce the final good, Y_t^P, as in Kimball (1995).[5] Let P_t be the price of the final good. The final good producer's optimization problem is given by

$$\max_{Y_{i,t}^P, Y_t^P} P_t Y_t^P - \int_0^1 p_{i,t} Y_{i,t}^P di, \qquad \text{s.t.} \quad \left[\int_0^1 \mathbb{G}\left(\frac{Y_{i,t}^P}{Y_t^P}; \eta_t^p \right) di \right] = 1,$$

where $p_{i,t}$ is the nominal price for the intermediate input $Y_{i,t}^P$, $\mathbb{G}$ is a strictly concave and increasing function satisfying $\mathbb{G}(1) = 1$, and η_t^p denotes a shock to the aggregator function that results in changes in the elasticity of goods demand. We assume η_t^p follows an ARMA(1,1) process as in Smets and Wouters (2007): $\hat{\eta}_t^p = \rho_p \hat{\eta}_{t-1}^p + \epsilon_t^p - \theta_p \epsilon_{t-1}^p$, where $\epsilon_t^p \sim i.i.d.N(0, \sigma_p^2)$. The first order conditions lead to the expression governing demand for intermediate good i,

$$Y_{i,t}^P = Y_t^P \mathbb{G}'^{-1} \left[\frac{p_{i,t}}{P_t} \int_0^1 \mathbb{G}' \left(\frac{Y_{i,t}^P}{Y_t^P} \right) \frac{Y_{i,t}^P}{Y_t^P} di \right]. \tag{1}$$

To simplify notation, we suppress the exogenous term η_t^p from the $\mathbb{G}$ function. Intermediate goods producers are monopolistic competitors in their product market. The production technology for good i is

$$Y_{i,t}^P = A_t^{1-\alpha} (K_{i,t})^\alpha \left(L_{i,t}^P\right)^{1-\alpha} - A_t \Omega, \tag{2}$$

where $\alpha \in (0,1)$ is the capital share, $L_{i,t}^P$ is the labor input employed by firm i, and $\Omega > 0$ represents fixed costs to production that grow at the rate of technological progress, given by A_t. The growth rate of A_t, $a_t \equiv \ln A_t - \ln A_{t-1}$, follows the AR(1) process,

$$a_t = (1 - \rho_a)\gamma + \rho_a a_{t-1} + \varepsilon_t^a, \quad \varepsilon_t^a \sim \text{i.i.d. } N\left(0, \sigma_a^2\right), \tag{3}$$

where γ defines the natural logarithm of the steady-state gross growth rate of technology. In aggregation, total labor employed by the private sector is

$$L_t^P = \int_0^1 L_{i,t}^P di. \tag{4}$$

Price rigidities are introduced by a Calvo (1983) mechanism. There is a probability $1 - \omega_p$ each period that an intermediate firm is allowed to reoptimize its price. Those who are not

[5]Relative to the commonly used Dixit-Stiglitz aggregator, the Kimball (1995) aggregator is more general. See Eichenbaum and Fisher (2007) and Smets and Wouters (2007) for a discussion.

allowed to re-optimize index their prices according to the rule[6]

$$p_{i,t} = \pi p_{i,t-1}, \tag{5}$$

where π is the steady-state inflation rate. Throughout the paper, steady-state values are denoted by variables without a time subscript.

Let $\beta \in (0,1)$ be the discount factor and λ_t be the household's marginal utility of consumption at time t. The intermediate firm i chooses its price $p^*_{i,t}$ to maximize

$$E_t \sum_{s=0}^{\infty} (\beta\omega_p)^s \frac{P_t \lambda_{t+s}}{P_{t+s}\lambda_t} \left[p^*_{i,t} \prod_{k=1}^{s} (\pi) - P_{t+s} mc_{t+s} \right] Y^P_{i,t+s},$$

subject to demand given by equation (1). $P_t\lambda_{t+s}/P_{t+s}\lambda_t$ denotes the nominal stochastic discount factor of the household, and $P_{t+s}mc_{t+s}$ denotes nominal marginal costs at time $t+s$.

2.2. **Labor Market.** The economy has a continuum of labor unions, indexed by $j \in [0,1]$, who supply differentiated labor inputs, $L_{j,t}$, to a perfectly competitive labor packer, as in Smets and Wouters (2007). A labor packer has two tasks. First, as is common in the literature, it assembles the composite labor, L_t, from differentiated labor inputs. Second, it allocates composite labor between public and private sectors, L^G_t and L^P_t. Both intermediate firms and the government demand composite labor, consisting of the same proportions of differentiated labor inputs ($L_{j,t}$).

The labor packer buys labor inputs from unions and produces the composite labor with the Kimball (1995) aggregator

$$\left[\int_0^1 \mathbb{G}_L \left(\frac{L_{j,t}}{L_t}; \eta^w_t \right) dj \right] = 1, \tag{6}$$

where $\mathbb{G}_L$ is a strictly concave and increasing function satisfying $\mathbb{G}_L(1) = 1$, and η^w_t denotes a shock to the aggregator function that results in changes in the elasticity of labor service demand. The labor packer takes each labor type's nominal wage rate $W_{j,t}$ as given. Solving

[6]We allow for an adjustment to trend inflation as in Gertler et al. (2008).

the profit maximization problem of the labor packer yields the demand function for labor type j:

$$L_{j,t} = L_t \mathbb{G}_L^{\prime -1} \left[\frac{W_{j,t}}{W_t} \int_0^1 \mathbb{G}_L^{\prime} \left(\frac{L_{j,t}}{L_t} \right) \frac{L_{j,t}}{L_t} dj \right], \tag{7}$$

where $W_{j,t}$ is the nominal wage rate for the jth labor input, and W_t is the nominal wage index of aggregate labor L_t. To simplify notation, we suppress the exogenous term η_t^w from the $\mathbb{G}_L$ function. Symmetrically to the final good, η_t^w follows an ARMA(1,1) process with parameters ρ_w and θ_w.

Similar to Bouakez et al. (2009), we allow for imperfect substitutability of labor inputs across the private and public production sectors to capture frictions in labor mobility. The total amount of composite labor is a constant-elasticity-of-substitution (CES) aggregate of the labor used in each sector. Thus,

$$L_t = \left[(1-\varphi)^{\frac{-1}{\mu}} \left(L_t^P \right)^{\frac{1+\mu}{\mu}} + \varphi^{\frac{-1}{\mu}} \left(L_t^G \right)^{\frac{1+\mu}{\mu}} \right]^{\frac{\mu}{1+\mu}}, \tag{8}$$

where φ is the steady-state share of composite labor worked in the public sector, and $\mu > 0$ is the intratemporal elasticity of substitution between public and private labor.

Solving the profit maximization problem yields

$$L_t^P = (1-\varphi) \left(\frac{W_t^P}{W_t} \right)^{\mu} L_t, \quad L_t^G = \varphi \left(\frac{W_t^G}{W_t} \right)^{\mu} L_t, \tag{9}$$

where W_t^P and W_t^G are the nominal wage rates paid in the private and public sectors. When μ is high, equation (9) implies that a fall in public wages relative to the aggregate nominal wage (W_t) leads to a larger decline in labor supplied to the public sector, implying a smaller friction in labor mobility.

Households are composed of several individuals with differentiated labor services. Households supply labor to intermediate labor unions, who set individual wages $W_{j,t}$ of the j labor varieties in order to maximize household utility. In line with Calvo's (1983) wage rigidity mechanism, each period a fraction $1 - \omega_w$ of unions are allowed to re-optimize their nominal wage $W^*_{j,t}$. The fraction ω_w of unions that cannot set their wage follow the rule

$$W_{j,t} = W_{j,t-1}(\pi_{t-1}e^{a_{t-1}})^{\chi^w}(\pi e^{\gamma})^{(1-\chi^w)}, \tag{10}$$

where $\chi^w \in [0,1]$ is the backward-looking component in the inflation and real wage growth process. Union profits are distributed in lump-sum dividends to households.

2.3. **Households.** A (large) representative household consists of a continuum of members over the unit square indexed by a pair $(j,k) \in [0,1]\times[0,1]$. The first dimension, j, denotes the type of labor service supplied by an individual, while the second dimension, k, determines an individual's disutility from work. Disutility from working is zero if the individual is unemployed and equal to $u^L_t \Theta_t k^{\kappa}$ if employed. As in Galí et al. (2012), Θ_t is a preference shifter (specified below) that is taken as given by the household, and u^L_t is a labor supply shock, which follows the AR(1) process

$$\ln u^L_t = (1-\rho_L)\ln u^L + \rho_L \ln u^L_{t-1} + \varepsilon^L_t, \quad \varepsilon^L_t \sim \text{i.i.d. } N\left(0, \sigma^2_L\right). \tag{11}$$

An individual's utility is given by

$$E_t \sum_{t=0}^{\infty} \beta^t u^b_t \left[\ln\left(C_t(j,k) - \theta \tilde{C}_{t-1}\right) - \mathbb{I}_t(j,k) u^L_t \Theta_t k^{\kappa}\right], \tag{12}$$

where $C_t(j,k)$ is the individual's consumption, $\tilde{C}_{t-1}$ is lagged aggregate consumption that is taken as given by each individual, $\theta \in [0,1)$ is the degree of external habit formation, and $\mathbb{I}_t(j,k)$ is an indicator for employment of the individual of type j,k. u^b_t is a general preference shock, following the AR(1) process,

$$\ln u^b_t = (1-\rho_b)\ln u^b + \rho_b \ln u^b_{t-1} + \varepsilon^b_t, \quad \varepsilon^b_t \sim \text{i.i.d. } N\left(0, \sigma^2_b\right). \tag{13}$$

Following Merz (1995), we assume there is full risk sharing of consumption by household members, so that $C_t(j,k) = C_t$. Integrating the individual utility over members leads to the representative household's utility:

$$E_t \sum_{t=0}^{\infty} \beta^t u^b_t \left[\ln\left(C_t - \theta \tilde{C}_{t-1}\right) - u^L_t \Theta_t \int_0^1 \frac{(L_t(j))^{1+\kappa}}{1+\kappa} dj\right], \tag{14}$$

where $\Theta_t \equiv Z_t^L \left(C_t - \theta \tilde{C}_{t-1}\right)^{-1}$ and Z_t^L evolves according to $Z_t^L = \left(Z_{t-1}^L\right)^{1-\theta_L} \left(C_t - \theta \tilde{C}_{t-1}\right)^{\theta_L}$. The preference shifter follows Galí et al. (2012) and allows for a small short-term wealth effect on labor depending on the size of $\theta_L \in (0,1)$.[7]

The final good is the numeraire of the economy, with a unit price P_t. The gross inflation rate for the CPI is then defined as $\pi_t \equiv \frac{P_t}{P_{t-1}}$. The real flow budget constraint for the household is

$$(1+\tau_t^C)C_t + B_t + I_t = (1-\tau_t^I)\left(\frac{W_t^h L_t}{P_t} + \frac{R_t^K v_t \bar{K}_{t-1}}{P_t}\right) + \frac{R_{t-1}B_{t-1}}{\pi_t} + Z_t + D_t - \Psi(v_t)\bar{K}_{t-1}, \quad (15)$$

where τ_t^I is the income tax rate, τ_t^C is the consumption tax rate, W_t^h is the aggregate nominal wage rate received by the household, Z_t is a lump-sum transfer from the government, D_t is the profits from intermediate goods firms and labor unions, I_t is gross investment, and B_t is the real holdings of a riskless, one-period, nominal government bond that pays a nominal rate of R_t at $t+1$. R_t^K is the nominal rental rate of effective capital, $K_t \equiv v_t \bar{K}_{t-1}$ where v_t is the capital utilization rate, and $\frac{R_t^K}{P_t} = r_t^K$ is the real rental rate. Changing capital utilization incurs a cost, $\Psi(v_t)\bar{K}_{t-1}$, where Ψ is an increasing, convex function in terms of v_t. In particular, we define a parameter $\psi \in [0,1)$ such that $\frac{\Psi''(1)}{\Psi'(1)} \equiv \frac{\psi}{1-\psi}$. In the steady state, it is assumed that $v = 1$ and $\Psi(1) = 0$. Given these assumptions, the dynamics are affected by ψ, but the steady state of the model, as shown in Appendix A, is independent of ψ.

Let δ be the capital depreciation rate. The law of motion for capital is

$$\bar{K}_t = (1-\delta)\bar{K}_{t-1} + u_t^i \left[1 - s\left(\frac{I_t}{I_{t-1}}\right)\right] I_t, \quad (16)$$

where $s(\cdot)$ is a positive adjustment function of changes in investment. As is common in the literature, the steady-state adjustment cost is characterized with $s(\gamma) = s'(\gamma) = 0$ and $s(\gamma)'' \equiv s > 0$. The investment adjustment cost shock, u_t^i, follows the AR(1) process,

$$\ln u_t^i = (1-\rho_i)\ln u^i + \rho_i \ln u_{t-1}^i + \varepsilon_t^i, \quad \varepsilon_t^i \sim \text{i.i.d. } N\left(0, \sigma_i^2\right). \quad (17)$$

[7] $\theta_L = 1$ corresponds to standard, separable preferences when $\Theta_t = 1$.

Preferences imply that the household-relevant, tax-adjusted marginal rate of substitution between consumption and employment for type j workers is: $MRS_t(j) \equiv u_t^L Z_t^L L_t(j)^\kappa (1+\tau_t^C)/(1-\tau_t^I)$. In turn, we define the (log) average marginal rate of substitution as $mrs_t \equiv \int_0^1 mrs_t(j)dj$. Each individual of type j,k will find it optimal to participate in the labor market if and only if

$$\frac{W_{j,t}}{P_t} \geq u_t^L Z_t^L k^\kappa \frac{(1+\tau_t^C)}{(1-\tau_t^I)}.$$

Let the marginal supplier of type j labor be denoted by $L_t^*(j)$: $\frac{W_{j,t}}{P_t} = u_t^L Z_t^L (L_t^*(j))^\kappa (1+\tau_t^C)/(1-\tau_t^I)$. We define the (log) aggregate participation as $l_t^* = \int_0^1 l_t^*(j)dj$ and (log) aggregate labor as $l_t = \int_0^1 l_t(j)dj$. Then, the unemployment rate u_t is defined as $u_t \equiv l_t^* - l_t$.[8]

2.4. **Government.** The government purchases final goods produced by the private sector (G_t^d) and combines it with composite labor (L_t^G) to produce its output, G_t. The value added of government production to aggregate output is

$$Y_t^G = G_t - G_t^d. \tag{18}$$

Government output is evaluated at its production costs as[9]

$$G_t = G_t^d + \frac{W_t^G}{P_t} L_t^G. \tag{19}$$

To finance its expenditures and interest payments, each period the government collects tax revenues and issues bonds.[10] The government budget constraint is given by

$$B_t + \underbrace{\tau_t^I \left(\frac{W_t^P}{P_t} L_t + r_t^K K_t \right) + \tau_t^C C_t}_{\equiv T_t \text{ tax revenue}} = \frac{R_{t-1}B_{t-1}}{\pi_t} + Z_t + G_t. \tag{20}$$

[8]This definition of the unemployment rate is very close to the conventional one, namely $1-(L_t/L_t^*)$, as mentioned by Galí et al. (2012).

[9]In national accounting, the value added of government output to GDP consists of compensation of general government employees and depreciation of fixed capital. Since the model does not have public capital, the value added of government production equals government compensation in the model.

[10]The state balanced-budget requirements generally refer to operating budgets, not to capital budgets for highways, buildings, etc. which are largely financed by debt. Also, many states have biennial balanced-budget rules. See National Conference of State Legislatures (2010) for a summary on state balanced-budget provisions.

The primary fiscal balance is defined as

$$FB_t = T_t - G_t - Z_t. \tag{21}$$

Fiscal policy instruments evolve according to the rules:

$$\frac{\tau_t^I}{\tau^I} = \left(\frac{\tau_{t-1}^I}{\tau^I}\right)^{\rho_{\tau^I}} \left(\frac{B_{t-1}}{s^b Y_{t-1}}\right)^{\gamma_{\tau^I}} \varepsilon_t^{\tau^I}, \tag{22}$$

$$\frac{\tau_t^C}{\tau^C} = \left(\frac{\tau_{t-1}^C}{\tau^C}\right)^{\rho_{\tau^C}} \left(\frac{B_{t-1}}{s^b Y_{t-1}}\right)^{\gamma_{\tau^C}} \varepsilon_t^{\tau^C}, \tag{23}$$

$$\frac{G_t^d}{g^d A_t} = \left(\frac{G_{t-1}^d}{g^d A_{t-1}}\right)^{\rho_g} \left(\frac{B_{t-1}}{s^b Y_{t-1}}\right)^{-\gamma_g} \varepsilon_t^{g}, \tag{24}$$

$$\frac{Z_t}{z A_t} = \left(\frac{Z_{t-1}}{z A_{t-1}}\right)^{\rho_z} \varepsilon_t^{z}, \tag{25}$$

where $s^b = \frac{B}{Y}$ is the steady-state debt-to-total output ratio, $g^d = \frac{G^d}{A}$ is the steady-state scaled government purchases of goods, and ε_t^x is a fiscal shock, log-normally distributed with mean zero and variance σ_x^2 for $x \in \{\tau^I, \tau^C, g, z\}$.

The baseline specification assumes that the real public wage rate responds to the real private wage rate as in Quadrini and Trigari (2007) and Bermperoglou et al. (2013). Since the government may not be able to observe the real private wage contemporaneously, we assume that real private wages enter the rule with a one-quarter lag:

$$\frac{W_t^G}{w^G P_t A_t} = \left(\frac{W_{t-1}^G}{w^G A_{t-1} P_{t-1}}\right)^{\rho_{wg}} \left[\left(\frac{W_{t-1}^P}{w^P P_{t-1} A_{t-1}}\right)^{\kappa_{wp}} \left(\frac{B_{t-1}}{s^b Y_{t-1}}\right)^{-\gamma_{wg}}\right] \varepsilon_t^{wg}, \tag{26}$$

where w^G and w^P are the steady-state scaled real public and private wage rates (see Appendix A.1), and ε_t^{wg} is the public wage shock, log-normally distributed with mean zero and variance σ_{wg}^2. Note that we specify the public wage rule in terms of the real wage rate. Thus adjustments in nominal public wages at a lower rate than inflation amount to changes in public wage policy.

The monetary authority follows a Taylor-type rule, given by

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left[\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{Y_t}{y A_t}\right)^{\phi_y}\right]^{1-\rho_R} \varepsilon_t^{m}, \tag{27}$$

where ε_t^m is log-normally distributed with mean zero and variance σ_m^2.

2.5. **Market Clearing.** The private goods market clearing condition is given by

$$Y_t^P = C_t + I_t + G_t^d + \Psi(v_t)\bar{K}_{t-1}. \tag{28}$$

Given equation (19), total output is

$$Y_t = Y_t^P + Y_t^G = C_t + I_t + G_t + \Psi(v_t)\bar{K}_{t-1}. \tag{29}$$

2.6. **Model Solution.** The equilibrium system of the model consists of optimality conditions for the household's, unions', firms' and labor packer's optimization problems, market clearing conditions, the government budget constraint, monetary and fiscal policy rules, and the stochastic processes for all shocks. We focus on a symmetric equilibrium in which all firms and unions that have the opportunity to set their prices and wages optimally at a given time choose the same ones. Since the model features a permanent shock to technology, we rewrite the model in terms of detrended variables, compute the log-linear approximation around the non-stochastic steady state, and solve the model with Sims (2001) algorithm. Appendix A describes the equilibrium conditions, the steady state, and the log-linearized equilibrium system.

3. Calibration and Estimation

The model is estimated with Bayesian inference methods and U.S. quarterly data from 1984Q1 to 2016Q4. Since monetary policy in the early 1980s underwent a transition to regain price stability, we start the sample in 1984Q1. Twelve observables are used to estimate the model, including the log difference of real consumption, investment, private and public sector wages, government spending on goods purchases, income tax revenue, consumption tax revenue, and government debt, the log difference of the GDP deflator, the log of private-sector employment, the Federal Funds rate, and the unemployment rate.

Our interest is on the effects of public wage changes by state and local (S&L) governments, so all fiscal data are measured at the S&L level.[11] Private and public wage data are constructed from NIPA compensation data divided by aggregate hours worked and scaled by the CPI to construct real wage measures.[12] Appendix B provides a detailed data description and the linkage between model variables and observables.

3.1. **Calibration.** Following the literature, we calibrate some parameters which are difficult to identify. Table 1 lists calibrated parameters. The discount factor, β, is set to 0.99, implying an annual steady-state real interest rate of 4 percent. The capital income share of total output, α, is set as 0.3. The quarterly depreciation rate for private capital, δ, is 0.025 so that the annual depreciation rate is 10 percent. Both the elasticities of substitution in the goods and labor markets are set to 8, implying that the markups in the product and labor markets are approximately 14 percent (or $\eta_w = \eta_p = 0.14$). This is consistent with the average price markup of U.S. firms which is around 10-15 percent (Basu and Fernald (1995)). The parameters that govern the curvature of Kimball's (1995) aggregators, ξ^p and ξ^w (see equations (A.41) and (A.42) in Appendix A.3), are set to 10 as in Smets and Wouters (2007).

In addition to some structural parameters, we calibrate the steady-state values of fiscal variables based on the average sample values. Using the net S&L government saving and interest payment data (NIPA Table 3.3, lines 31 and 27), we compute the average primary fiscal balance as a share of output as 0.5%, which implies that the debt-to-annual output ratio is 0.12 in the steady state. The sample average share of government compensation of S&L governments to output, $\frac{w^G L^G}{Y}$, is 0.077. Similarly, the government purchases of goods to output, $\frac{G^d}{Y}$, is set to 0.045, and the income and consumption tax revenues-to-output ratios

[11]The literature often focuses on one level of government. For instance, Leeper et al. (2017) consider only the federal level. Given the majority of public compensation is at the S&L level—over 70% in our sample—we focus on this level of government.

[12]We also considered wage data constructed from real ECI compensation for private and public wages. The mean estimates of serial correlations for price and wage markups are virtually 1 in this case, suggesting that the transformed data may not be stationary.

are 0.028 and 0.108.[13] For all computations, output is defined as the sum of government consumption, private consumption, and total investment (without net exports), in line with the output definition in the model. To calibrate the public-sector wage premium in the steady state, we resort to the cost per hour worked measured by total compensation for S&L governments and private industries. The average ratio of the private to public wage rates from 2004 to 2016 is 0.69.[14]

3.2. **Prior Distributions.** Table 2 lists the prior distributions. Most priors use common functional forms and ranges employed by the literature, e.g., Smets and Wouters (2007), Leeper et al. (2010), Traum and Yang (2011), and Galí et al. (2012). The discussion here focuses on parameters related to public-sector labor and wages, which are not commonly estimated. The prior for μ (the elasticity of substitution between public and private labor) is set to a gamma distribution with mean of 3 and standard deviation of 1. Given little guidance from the literature, we assume a dispersed prior. Horvath (2000) adopts the CES aggregator to model varieties of sectoral labor inputs. Using U.S. data of two-digit Standard Industrial Classification levels, he estimates that the sectoral elasticity is about 1, but alternative estimations have much higher values. Thus, we set a higher prior mean of 3. To set the prior for κ_{wp} (the response of public wages to private wages), we consider Quadrini and Trigari's (2007) estimates for the elasticity of the private wage rate to public wage rate, ranging from 0.19 to 0.94.[15] Our prior has a normal distribution with a mean of 0.5 and standard deviation of 0.2 to cover their estimated range and allows for a potentially negative correlation. For γ_{wg} (the response to lagged government debt), we use the same prior assumed for the other fiscal adjustment parameters (γ_τ^I, γ_τ^C, and γ_g), which have normal distributions of mean 0.2

[13] See Appendix B for data sources.

[14] The two data series—total compensation cost per hour worked for all occupations of S&L governments (series ID CMU3010000000000D) and of private industries (series ID CMU2010000000000D)—are published by the BLS. Since the data are only available from 2004, we do not estimate the model with this series, as it is to short.

[15] Their specification is a contemporaneous response between $\ln w_t^G$ and $\ln w_t^P$.

and standard deviation 0.03. Lastly, the other two public wage parameters, ρ_{wg} and σ_{wg}, follow the priors of other shocks.

3.3. **Bayesian Estimation.** We construct posterior distributions, combining priors with the likelihood function, which is calculated using the Kalman filter. We sample 2 million draws using the random-walk Metropolis-Hastings algorithm.[16] A step size of 0.31 yields an acceptance rate of 0.30. The first 500,000 draws are discarded and the sample is thinned by every 100 draws to remove serial correlation between the draws, leaving a final sample size of 15,000. Table 2 shows the means and standard deviations of the prior distributions, and the modes, means, standard deviations, and 90-percent intervals of the posterior distributions for the baseline estimation. Figure 2 displays the prior-posterior distribution plots of all estimated parameters.

The estimation results in Table 2 and Figure 2 show that overall the data are informative about the estimated parameters. Most estimated values for the common structural and monetary policy parameters (100γ, κ, θ, ω_p, s, χ_w, ϕ_π, and ϕ_y) are similar to those in Smets and Wouters (2007) and Traum and Yang (2011). The posterior mean of the wage rigidity parameter, $\omega_w = 0.18$, is much lower than its prior. This relatively low estimate of the wage rigidity shows including unemployment in a NK model reduces the nominal wage rigidity, as first pointed out by Galí et al. (2012). Importantly, the elasticity of labor substitutability, μ, has a mean of 1.50, implying some mobility friction between public and private sectors.

On fiscal adjustments, S&L governments systematically relied on increasing income and consumption taxes or decreasing goods purchases to stabilize debt growth; γ_{τ^I}, γ_{τ^C}, and γ_g have significantly positive 90-percent intervals. In contrast, the 90-percent posterior interval of γ_{wg} ($[-0.002, 0.042]$) includes zero, suggesting no significant response. This implies

[16]Diagnostic results to ensure the convergence of the MCMC chain are available upon request. We initiate the Metropolis-Hastings algorithm at the posterior mode. To calculate the posterior mode, we first compute the posterior likelihood at 5000 initial draws, and the 25 draws with the highest posterior likelihood are used to initialize a search for the posterior mode. Among the 25 modes searches for the baseline specification, 21 converge to the same values which we denote as the posterior mode, 1 search fails to converge, and the remaining 3 converge to values with lower likelihood numbers.

that public wage reductions have not been used systematically to stabilize debt by S&L governments, despite their recent discretionary use to improve the fiscal balance.

Another parameter of interest is κ_{wp}, which has a posterior mean of 0.23 and a 90-percent interval of $[0.15, 0.31]$. This response magnitude falls in the range of estimates in Quadrini and Trigari (2007). The positive relationship between the two wages indicates that the government systematically accounts for private wage movements when setting public wages.

4. The Macroeconomic Effects of Public Wage Reductions

To understand the effects of public wage reductions, we analyze impulse responses to a negative public wage shock. We compare the responses to those from a negative goods purchase shock, which is commonly analyzed in the literature. We focus our discussion on key parameters that influence the responses of private output and wages. We then analyze the role of public wages in the recent dynamics of the primary fiscal balance and total output.

4.1. **Impulse Responses: Public Wage vs. Goods Purchase Shocks.** Figures 3 and 4 present impulse responses to government spending reductions triggered by a negative public wage and a goods purchase shock. The solid lines denote the posterior mean responses and dotted-dashed lines are the 90-percent bands simulated from the posterior distributions. To facilitate comparison, the shock sizes are scaled such that each type of spending reduction equals one percentage point of the steady-state output. All variables are expressed in percent deviation from the steady state except for those specified in parentheses. The x-axis indicates years after the initial shock.

A fiscal consolidation—by cutting public wages or goods purchases—increases the primary fiscal balance and lowers government debt. This generates a positive wealth effect to households, as lower debt requires less future taxation and encourages current consumption. For a goods purchase reduction, this effect unambiguously increases consumption (Figure 4). A public wage reduction, however, also lowers households' wage income from working in the public sector. In equilibrium, the positive wealth effect is largely offset by the negative wage income effect, and consumption responds little–the 90-percent bands largely encompass zero (Figure 3).

Private output also responds differently to the two shocks. While total output falls following reductions in either type of spending, private output *increases* with a public wage reduction. This result is consistent with the empirical findings in Alesina et al. (2002) and Alesina and Ardagna (2010).[17] Following a decrease in public wages, investment increases as less public borrowing lowers the equilibrium real interest rate and the income tax rate, which raises the after-tax return to investment. Since consumption responds little, increased investment boosts overall goods demand, leading private firms with sticky prices to produce more. Although investment and consumption both rise with a goods purchase reduction, aggregate goods demand falls because of reduced government purchases of goods. As a result, private firms cut labor demand, lowering equilibrium private employment and output.

Overall, a reduction in either public wages or goods purchases increases unemployment, but the sectoral labor effects are flipped across the two types of consolidations. A reduction in goods purchases lowers private labor and increases public labor, because of lower aggregate goods demand, resulting in labor reallocation from the private to public sector. In contrast, a reduction in public wages makes working in the public sector less attractive, resulting in labor reallocation from the public to private sector. However, the estimated labor friction prevents the private sector from quickly absorbing the increase in job seekers from the public sector, leading to an increase in unemployment with a public wage reduction.

Following decreased aggregate demand, inflation falls with a reduction in government purchases of goods. The inflation response with a public wage reduction also is negative but with a much smaller magnitude. Although labor reallocation effects lead private real wages

[17]These two papers do not distinguish between total and private output. In general, the empirical literature has not formed a consensus on expansionary fiscal consolidations. Using a narrative approach with 173 identified fiscal adjustment episodes in OECD countries, Guajardo et al. (2014) conclude that fiscal consolidations are contractionary to private demand and GDP.

to fall, higher aggregate goods demand generates upward pressure on inflation, offsetting some of the negative responses.

4.2. **Government Spending Multipliers.** Table 3 compares the government spending multipliers for output and its components under the baseline model. The present-value multiplier k quarters after a shock is computed as follows

$$\frac{E_t \sum_{j=0}^{k} (\prod_{i=0}^{j} r_{t+i}^{-1}) \Delta Y_{t+j}}{E_t \sum_{j=0}^{k} (\prod_{i=0}^{j} r_{t+i}^{-1}) \Delta G_{t+j} \text{ or } \Delta w_{t+j}^{G} L_{t+j}^{G}}, \tag{30}$$

where Δ denotes the level difference in output or government spending relative to its steady-state values. The discount factor, r_t, is constructed from the transitional path of the real interest rate.

While the two types of spending have similar total output multipliers on impact (0.87 and 0.97), they have the opposite signs for private output: 0.97 for goods purchases and -0.03 for public wages. The difference is larger at longer horizons: two years after the shock, the private output multiplier for government compensation becomes more negative at -0.34, compared to 0.23 for goods purchases. A negative multiplier for private output means that a fiscal consolidation with a public wage reduction is expansionary for private output (despite the decline in total output). Conversely, if public wages are increased to stimulate the economy, the negative multiplier implies that private output would decrease, opposite to the effect of an increase in goods purchases.

To gauge the effectiveness of spending reductions in improving the fiscal balance, we also compute the fiscal balance multiplier by replacing ΔY_{t+j} with ΔFB_{t+j} in equation (30). Based on the baseline posterior mean estimates, a one-dollar spending reduction in government compensation or goods purchases increases the fiscal balance by about 0.9 dollars on impact.

4.3. **Public and Private Wage Interactions.** In our model, private and public wage interactions depend on two main channels, exerting opposing influences on the private wage.

The equilibrium private wage movement crucially depends on the relative strength of nominal rigidities and the sectoral mobility friction.

The first channel works through labor reallocation. A public-wage reduction makes working in the public sector less attractive, inducing labor movements from the public to the private sector (as made clear by equation (9)). Higher labor supply in the private sector exerts downward pressure on real private wages. The strength of the reallocation effect depends on 1) the labor mobility friction (captured by the substitutability between the two types of labor) and 2) nominal wage rigidities. When the mobility friction is low (a bigger μ), the reallocation effect is stronger, resulting in a larger increase in private-sector labor and more downward pressure on private wages. When nominal wages are less rigid (a smaller ω_w), private wages are allowed to adjust more, reinforcing the labor reallocation effect and resulting in a larger increase in the labor supply to the private sector.

The second channel works through increased goods demand. The positive effect on aggregate demand from a public-wage reduction (as discussed in Section 4.1) exerts upward pressure on goods prices. When goods prices are more rigid, they are more sluggish to adjust, limiting the upward price adjustment pressure. Sluggish prices also lower firms' profits, bringing a negative income effect to households and suppressing some of the positive goods demand from a public-wage reduction. As goods demand increases less, firms hire less labor, resulting in a lower private wage, and a smaller increase in private output. The right column of Figure 5 confirms that a more rigid goods price ($\omega_p = 0.76$ vs. $\omega_p = 0.01$) leads to a bigger decline in private wages and a smaller expansionary effect on private output.[18]

The left and middle columns of Figure 5 compare the impulse responses to a negative 1% public-wage shock across different μ's and ω_w's. The two alternative values of μ are the boundary values of the 90-percentile interval (0.98 and 2.10) of the posterior distribution. The left column of Figure 5 confirms that a lower labor mobility friction (a bigger μ) leads to

[18] For all other estimated parameters, the values are set to their posterior means.

a lower private wage following a public wage reduction. The alternative value of $\omega_w = 0.01$ represents a case of virtually flexible nominal wages, and the value $\omega_w = 0.75$ presents a value for the nominal wage rigidity often obtained in the estimated DSGE model without unemployment for the U.S. (e.g., Smets and Wouters (2007)). When private nominal wages are sufficiently rigid ($\omega_w = 0.75$), the private wage response can reverse its sign: A higher degree of nominal wage rigidity weakens the labor reallocation effect, and its downward pressure on private wages is dominated by the upward pressure from the positive goods demand channel, leading to an increase in private wages following a public wage reduction. While our baseline estimation implies that private wages decline following a public wage reduction, we find that whether private wages comove with an exogenous change in public wages depends crucially on the degree of the nominal wage rigidity.

4.4. **Historical Decomposition.** The impulse responses in the baseline analysis show that an exogenous negative public wage shock increases the fiscal balance, as shown in Figure 3. To analyze their quantitative importance in recent times, Figures 6 and 7 present historical decompositions for the primary fiscal balance and total output. These decompositions are based on smoothed estimates of the structural shocks from the two-sided Kalman filter at the posterior mean.

Figure 6 shows that between 2009 and 2015, public wage shocks—along with other fiscal shocks, such as tax increases and goods purchase reductions—made a substantial contribution to the increase in the primary fiscal balance of S&L governments. Structural shocks, on the other hand, contributed negatively to lowering the fiscal balance: as negative structural shocks slowed economic activity, they lowered tax bases and revenues, and hence deteriorated the fiscal position.

As for total output, Figure 7 shows that the structural shocks dominated the output dynamics after 2008, while policy shocks only had minor influence. Since reduced public wage rates directly lowered the value added of government output to total output, they mostly worked in the same direction as structural shocks to lower total output after 2009. Given the small negative impact of fiscal consolidations by S&L governments on total output, our analysis does not support the conjecture that the decline and slow rebound of government compensation or other fiscal consolidation measures are a significant contributor to the slow recovery from the Great Recession in the U.S. (Morrissey (2014) and Kellar (2015)).[19]

5. Sensitivity Analysis

Our baseline analysis finds that a public wage cut by S&L governments is slightly expansionary for private output. We now consider the robustness of these results to two alternative specifications, which are summarized in Table 4.[20] Specification 1 reproduces the baseline estimation (as in Table 2), while specifications 2 and 3 allow public services to enter the utility function and to enter the production function of intermediate goods firms, respectively. Table 5 presents log-marginal data densities calculated using Geweke's (1999) modified harmonic mean estimator with a truncation parameter of 0.5. The table also reports Bayes factors relative to the baseline model, which is most favored by the data.

5.1. **Utility Enhancing Public Services.** Our result that private output can rise in response to a public wage reduction is in line with the theoretical finding in Bermperoglou et al. (2017). Their result relies on low complementarity between private consumption and public services in a model with nominal price rigidities.[21] When the complementarity is low (or the substitution elasticity is high), a reduction in public wages, and hence public services, directly boosts private consumption, adding to aggregate demand. In our environment with both price and wage rigidities, public wage reductions can be expansionary even if public services are neither complements nor substitutes to private consumption. In light

[19]In the U.K., a similar argument has been made; lifting the public wage growth cap was argued to be an effective tool to stimulate aggregate demand (see Reed (2014)).

[20]The detailed results of the posterior distributions are available upon request.

[21]Bermperoglou et al.'s (2017) figures are in terms of a positive public wage shock.

of the competing economic channels for an expansionary public wage reduction, we estimate a revised model with utility enhancing public services.

We follow Leeper et al. (2017) to assume that the household derives utility from composite consumption, C_t^*, consisting of private consumption (C_t) and public services (Y_t^G). Equation (14) is modified as

$$E_t \sum_{t=0}^{\infty} \beta^t u_t^b \left[\ln \left(C_t^* - \theta \tilde{C}_{t-1}^* \right) - u_t^L \Theta_t \int_0^1 \frac{(L_t(j))^{1+\kappa}}{1+\kappa} \right] dj, \tag{31}$$

where $C_t^* \equiv C_t + \alpha_G Y_t^G$. Parameter α_G governs the degree of substitutability of the consumption goods: when $\alpha_G < 0$ (> 0), private and public consumption are complements (substitutes). The household values composite consumption relative to a habit stock defined in terms of lagged aggregate composite consumption ($\tilde{C}_{t-1}^*$). Following Leeper et al. (2017), we assume that α_G has a uniform prior over -1.5 to 1.5, indicating equal probability that public services are a substitute or a complement to private consumption.

Specification 2 of Table 5 shows that the Bayes factor of this specification relative to the baseline is $e^{2.8}$, suggesting the baseline model is slightly preferred to this specification. The utility enhancing parameter changes little, as the 90-percent interval of α_G's posterior distribution encompasses zero ($[-0.12, 0.11]$). In addition, the two specifications yield very similar estimates of all other parameters. Comparing columns 2 to 1 of Figure 8 shows that the responses of private output, labor, and the private wage rate under utility enhancing public services are almost the same as those in the baseline. Given that the estimated value of α_G encompasses zero, we do not find support for public services acting as a complement or substitute with private consumption.[22]

5.2. **Productive Public Services.** In specification 3, we consider productive public services, such as maintaining law and order, that may raise private productivity. Following Ardagna (2007), Pappa (2009), and Bandeira et al. (2018), we allow public services to enter

[22]Kormilitsina and Zubairy (2016) also do not find support for utility enhancing public goods in an estimated model with S&L and federal U.S. data that abstracts from modeling public compensation.

the private production function by modifying equation (2) as

$$Y_{i,t}^{P}=A_{t}^{1-\alpha}\left(K_{i,t}\right)^{\alpha}\left(L_{i,t}^{P}\right)^{1-\alpha}\left(\frac{Y_{t}^{G}}{\int_{0}^{1}Y_{i,t}^{P}+A_{t}\Omega}\right)^{\frac{\nu}{1-\nu}}-A_{t}\Omega. \tag{32}$$

We assume that government goods are rival but non-excludable as in Barro and Sala-I-Martin (1992). To ensure an aggregate constant-returns-to-scale production function before fixed costs, the externality of Y_t^G at the firm level is relative to aggregate output before fixed costs, as in Drautzburg and Uhlig (2015). We estimate ν using a dispersed prior with a gamma distribution of mean 0.05 and standard deviation of 0.02. The mean estimate of ν is 0.008 with a 90 percent confidence interval $[0.004, 0.013]$, suggesting that public services are not very productive in the sample. Figure 8 shows that the specification of productive public services (the third column) implies that following a public wage reduction, the degree of private output does not increase as much as the response of the baseline estimation (the first column).

When public services are productive, a public wage reduction acts like a negative technology shock, which lowers the productivity of private production factors. As a result, private labor becomes less productive, and the baseline positive investment response (from the positive wealth effect of less public spending) is mitigated by the decreased marginal product of capital, offsetting some of the original productive effect from the reduced public wage in the baseline model, as shown in Figure 8. However, we note that if public services are sufficiently productive, the negative effects from less productive services can dominate the original positive demand effect. In this case, public wage reductions can be contractionary for private output (results available on request).

Overall, our main conclusions that public wage reductions are slightly expansionary and real private wages fall in the short run hold across the two alternative estimated specifications.

6. Conclusion

We study the effects of public wage reductions by U.S. S&L governments using an estimated New Keynesian model with unemployment, a public production sector, and a sectoral labor mobility friction. We find that public wage reductions can be expansionary when public services are relatively unproductive. In addition, we find empirically relevant nominal wage and price rigidities, in combination with the sectoral labor mobility friction, are important for the interaction between public and private wage dynamics. Our baseline estimation finds that a public wage reduction leads real private wages to fall. Model counterfactuals show that this dynamic can be reversed when private nominal wages are sufficiently rigid. Historical decompositions suggest that public wage reductions helped increase the fiscal balance of S&L governments after the Great Recession but only played a minor role in the slow recovery after mid-2009 in the U.S.

Although there is debate in the literature on whether a fiscal consolidation can be expansionary, we find that private output multipliers have opposite signs for public wage spending and government purchases of goods. A negative (positive) private output multiplier means that a public wage (goods purchase) reduction is expansionary (contractionary). Alternatively, with a fiscal stimulus, our multiplier results imply that a public wage increase slightly contracts private output, while a goods purchase increase expands private output.

Appendix A. The Derivation of Log-Linearized Model

The appendix includes the equilibrium system, the steady state, and the log-linearized system of the model.

A.1. **The Equilibrium System.** We define Λ_t as the Lagrange multiplier associated with the savers' budget constraint, $\Lambda_t q_t$ as the Lagrange multiplier associated with the capital accumulation equation. Since the economy features a permanent shock to technology, several variables are not stationary. In order to induce stationarity, we perform a change of variables and define: $y_t = \frac{Y_t}{A_t}$, $y_t^P = \frac{Y_t^P}{A_t}$, $y_t^G = \frac{Y_t^G}{A_t}$, $c_t = \frac{C_t}{A_t}$, $i_t = \frac{I_t}{A_t}$, $\bar{k}_t = \frac{\bar{K}_t}{A_t}$, $k_t = \frac{K_t}{A_t}$, $g_t = \frac{G_t}{A_t}$, $g_t^d = \frac{G_t^d}{A_t}$, $b_t = \frac{B_t}{A_t}$, $z_t = \frac{Z_t}{A_t}$, and $\lambda_t = \Lambda_t A_t$. Also, we define $r_t^K \equiv \frac{R_t^K}{P_t}$, $w_t \equiv \frac{W_t}{P_t A_t}$, $w_t^P = \frac{W_t^P}{A_t P_t}$, $w_t^G = \frac{W_t^G}{A_t P_t}$, and $mc_t = \frac{MC_t}{P_t}$. The equilibrium system consists of the following system.

- FOC for consumption:

$$\lambda_t(1+\tau_t^c) = \frac{u_t^b}{c_t^* - \theta c_{t-1}^* e^{-u_t^a}} \tag{A.1}$$

- c^* definition:

$$c_t^* = c_t + \alpha_g y_t^G \tag{A.2}$$

- Z^L process:

$$z_t^L = \left(z_{t-1}^L e^{-u_t^a}\right)^{1-\theta_L} \left(c_t^* - \theta c_{t-1}^* e^{-u_t^a}\right)^{\theta_L} \tag{A.3}$$

- Household's FOC for government bond:

$$\lambda_t = \beta E_t \frac{\lambda_{t+1} e^{-u_{t+1}^a} R_t}{\pi_{t+1}} \tag{A.4}$$

- Household's FOC for investment:

$$\begin{aligned} 1 =& q_t u_t^i \left[1 - s\left(\frac{i_t e^{a_t}}{i_{t-1}}\right) - s'\left(\frac{i_t e^{a_t}}{i_{t-1}}\right)\left(\frac{i_t e^{a_t}}{i_{t-1}}\right)\right] \\ &+ \beta E_t \left[q_{t+1} u_{t+1}^i \frac{\lambda_{t+1} e^{-u_{t+1}^a}}{\lambda_t} s'\left(\frac{i_{t+1} e^{a_{t+1}}}{i_t}\right)\left(\frac{i_{t+1} e^{a_{t+1}}}{i_t}\right)^2\right] \end{aligned} \tag{A.5}$$

- Household's FOC for capital:

$$q_t = E_t \beta \frac{\lambda_{t+1} e^{-u_{t+1}^a}}{\lambda_t} \left[(1-\tau_{t+1}^I) r_{t+1}^K v_{t+1} - \Psi(v_{t+1}) + (1-\delta) q_{t+1}\right] \tag{A.6}$$

- Law of motion for capital:

$$\bar{k}_t = (1-\delta)\,\bar{k}_{t-1} e^{-a_t} + u_t^i \left[1 - s\left(\frac{i_t e^{a_t}}{i_{t-1}}\right)\right] i_t \tag{A.7}$$

- Intermediate firm's FOC for prices:

$$E_t \sum_{s=0}^{\infty} (\beta\omega_p)^s \lambda_{t+s} y^P_{i,t+s}(1+\tilde{\Theta}_{t,t+s}) \left(\frac{p^*_t}{P_t}\right) \prod_{k=1}^{s} \left[\frac{\pi}{\pi_{t+k}}\right]$$
$$= E_t \sum_{s=0}^{\infty} (\beta\omega_p)^s \lambda_{t+s} \tilde{\Theta}_{t,t+s} mc_{t+s} y^P_{i,t+s} \tag{A.8}$$

where

$$y^P_{i,t+s} = \mathbb{G}'^{-1}(z_{i,t+s}) y^P_{t+s} \tag{A.9}$$
$$z_{t+s} = \frac{p^*_t}{P_t} \prod_{k=1}^{s} \left[\frac{\pi}{\pi_{t+k}}\right] \tilde{\Xi}_{t+s} \tag{A.10}$$
$$\tilde{\Xi}_{t+s} = \int_0^1 \mathbb{G}' \left(\frac{y^P_{i,t+s}}{y^P_{t+s}}\right) \frac{y^P_{i,t+s}}{y^P_{t+s}} di \tag{A.11}$$
$$\tilde{\Theta}_{t,t+s} = \left[\mathbb{G}'^{-1}(z_{t+s})\right]^{-1} \frac{\mathbb{G}'\left[\mathbb{G}'^{-1}(z_{t+s})\right]}{\mathbb{G}''\left[\mathbb{G}'^{-1}(z_{t+s})\right]} \tag{A.12}$$

- Aggregate price index:

$$1 = (1-\omega_p)\frac{p^*_t}{P_t} \mathbb{G}'^{-1}\left[\frac{p^*_t}{P_t}\tilde{\Xi}_t\right] + \omega_p \left(\frac{\pi}{\pi_t}\right) \mathbb{G}'^{-1}\left[\left(\frac{\pi}{\pi_t}\right)\tilde{\Xi}_t\right] \tag{A.13}$$

- Unions' FOC for wages (combined with household labor supply):

$$E_t \sum_{s=0}^{\infty} (\beta\omega_w)^s \lambda_{t+s} \left[(1+\tilde{\Theta}^L_{t,t+s}) w^*_t \Pi^w_{t,t+s}\right] L_{j,t+s}$$
$$= E_t \sum_{s=0}^{\infty} (\beta\omega_w)^s \lambda_{t+s} \left[\tilde{\Theta}^L_{t,t+s} \frac{u^L_t z^L_{t+s} (\tilde{L}_{t+s})^\kappa (1+\tau^C_{t+s})}{(1-\tau^I_{t+s})}\right] L_{j,t+s} \tag{A.14}$$

where

$$\tilde{L}_{t+s} = \mathbb{G}'^{-1}_L \left[z^{lab}_{t+s}\right] L_{t+s} \tag{A.15}$$
$$z^{lab}_{t+s} = \frac{w^*_t}{w_{t+s}} \Pi^w_{t,t+s} \Xi^L_{t+s} \tag{A.16}$$
$$\Pi^w_{t,t+s} = \prod_{k=1}^{s} \left(\frac{\pi_{t+k-1} e^{a_{t+k-1}}}{\pi e^\gamma}\right)^{\chi^w} \left(\frac{\pi_{t+k} e^{a_{t+k}}}{\pi e^\gamma}\right)^{-1} \tag{A.17}$$
$$\Xi^L_{t+s} \equiv \int_0^1 \mathbb{G}'_L \left(\frac{L_{j,t+s}}{L_{t+s}}\right) \frac{L_{j,t+s}}{L_{t+s}} dj \tag{A.18}$$
$$\tilde{\Theta}^L_{t,t+s} = [\mathbb{G}'^{-1}_L(z^{lab}_{t+s})]^{-1} \frac{\mathbb{G}'_L[\mathbb{G}'^{-1}_L(z^{lab}_{t+s})]}{\mathbb{G}''_L[\mathbb{G}'^{-1}_L(z^{lab}_{t+s})]} \tag{A.19}$$

- Aggregate wage evolution:

$$w_t = (1-\omega_w)(w_t^*)\mathbb{G}_L'^{-1}\left[\frac{w_t^*}{w_t}\Xi_t^L\right] \tag{A.20}$$
$$+\omega_w\left(\frac{\pi_{t-1}e^{a_{t-1}}}{\pi e^\gamma}\right)^{\chi_w}\left(\frac{\pi e^\gamma}{\pi_t e^{a_t}}\right)w_{t-1}\mathbb{G}_L'^{-1}\left[\left(\frac{\pi_{t-1}e^{a_{t-1}}}{\pi e^\gamma}\right)^{\chi_w}\left(\frac{\pi e^\gamma}{\pi_t e^{a_t}}\right)\frac{w_{t-1}}{w_t}\Xi_t^L\right]$$

- Production function:

$$y_{i,t}^P = (k_{i,t})^\alpha \left(l_{i,t}^P\right)^{1-\alpha}\left(\frac{y_t^G}{\int_0^1 y_{i,t}^P + \Omega}\right)^{\frac{\nu}{1-\nu}} - \Omega \tag{A.21}$$

- Capital-labor ratio:

$$\frac{k_{i,t}}{l_{i,t}^P} = \frac{w_t^P}{r_t^K}\frac{\alpha}{1-\alpha} \tag{A.22}$$

- Goods market equilibrium:

$$y_t^P = c_t + i_t + g_t^d + \Psi(v_t)\bar{k}_{t-1}e^{-a_t} \tag{A.23}$$

- Government budget constraint:

$$b_t + \tau_t^I\left(w_t L_t + r_t^K k_t\right) + \tau_t^C = \frac{R_{t-1}b_{t-1}}{\pi_t e^{a_t}} + z_t + g_t \tag{A.24}$$

- Household's FOC for capital utilization:

$$(1-\tau_t^I)r_t^K = \psi'(v_t) \tag{A.25}$$

- Effective capital:

$$k_t = v_t\bar{k}_{t-1}e^{-a_t} \tag{A.26}$$

- Marginal cost:

$$mc_t = \frac{\left(w_t^P\right)^{1-\alpha}\left(r_t^K\right)^\alpha\left(\frac{y_t^G}{\int_0^1 y_{i,t}^P+\Omega}\right)^{\frac{-\nu}{1-\nu}}}{(1-\alpha)^{1-\alpha}\alpha^\alpha} \tag{A.27}$$

- Value-added of government production:

$$y_t^G = w_t^G L_t^G \tag{A.28}$$

- Total output:

$$y_t = y_t^P + y_t^G \tag{A.29}$$

- Government output:

$$g_t = g_t^d + w_t^G L_t^G \tag{A.30}$$

- Labor market equilibrium:

$$L_t = \left[(1-\varphi)^{\frac{-1}{\mu}}\left(L_t^P\right)^{\frac{1+\mu}{\mu}} + \varphi^{\frac{-1}{\mu}}\left(L_t^G\right)^{\frac{1+\mu}{\mu}}\right]^{\frac{\mu}{1+\mu}}, \tag{A.31}$$

- Public sector wage:

$$w_t^G = \left(\frac{L_t^G}{\varphi L_t}\right)^{\frac{1}{\mu}} w_t \tag{A.32}$$

- Aggregate wage index:

$$w_t = \left[(1-\varphi)\left(w_t^P\right)^{1+\mu} + \varphi\left(w_t^G\right)^{1+\mu}\right]^{\frac{1}{1+\mu}} \tag{A.33}$$

A.2. **Steady State.** By assumption, in the steady state $v = 1$, $\Psi(1) = 0$, $s(\gamma) = s'(\gamma) = 0$. In addition, we assume that $\pi = 1$, implying $R = \frac{\gamma}{\beta}$. We set Ω so that steady state profits are zero. In steady state $\mathbb{G}'^{-1}(z) = 1$, $\mathbb{G}_L'^{-1}(z_j^L) = 1$, and $\Xi^L = \mathbb{G}_L'(1)$.

$mc = 1 + \frac{\mathbb{G}''(1)}{\mathbb{G}'(1)}$. Then the gross markup is $1 + \eta^P = \frac{\epsilon^p(1)}{\epsilon^p(1)-1}$ where the elasticity of demand is $\epsilon^p(1) = -\frac{\mathbb{G}'(1)}{\mathbb{G}''(1)}$. In addition, equation (A.14) implies that in steady state $\frac{L^\kappa}{w(1-\tau)(c-\theta c e^{-\gamma})^{-1}} = 1 + \frac{\mathbb{G}_L''(1)}{\mathbb{G}_L'(1)}$. Then the gross wage markup is defined as $1+\eta^w = \frac{\epsilon^w(1)}{\epsilon^w(1)-1}$ where the elasticity of demand is $\epsilon^w(1) = -\frac{\mathbb{G}_L'(1)}{\mathbb{G}_L''(1)}$. In the steady state we can derive

$$r^K = \frac{e^\gamma - \beta(1-\delta)}{\beta(1-\tau^I)}$$

$$\psi'(1) = \left(1-\tau^I\right) r^K$$

$$\frac{y^P}{y} = 1 - \frac{y^G}{y}$$

$$\frac{\Omega}{y^P} = \eta^p$$

$$w^P = \left[\frac{(1-\alpha)^{1-\alpha}(\alpha)^\alpha}{(r^K)^\alpha(1+\eta^P)}\left(\frac{\frac{y^G}{y}}{\frac{y^P}{y} + \frac{\Omega}{y^P}\frac{y^P}{y}}\right)^{\frac{\nu}{1-\nu}}\right]^{\frac{1}{1-\alpha}}$$

$$w^G = w^P \frac{1}{\frac{w^P}{w^G}}$$

$$\frac{L^G}{y} = \frac{y^G}{y}\frac{1}{w^G}$$

$$\frac{k}{L^P} = \frac{w^P \alpha}{r^K(1-\alpha)}$$

$$\frac{L^P}{y^P} = \left[\left(1 + \frac{\Omega}{y^P}\right)\left(\frac{k}{L^P}\right)^{-\alpha(1-\nu)}\left(\frac{y^G}{y}\frac{y}{y^P}\right)^{-\nu}\right]^{\frac{1}{1-\nu}}$$

$$\frac{L^G}{y^P} = \frac{L^G}{y}\frac{y}{y^P}$$

$$\frac{L^P}{L^G} = \frac{L^P}{y^P}\frac{y^P}{L^G}$$

$$\frac{i}{y^P} = [1-(1-\delta)e^{-\gamma}]e^{\gamma}\frac{k}{L^P}\left(\frac{y^P}{L^P}\right)^{-1}$$

$$\frac{c}{y^P} = 1 - \frac{i}{y^P} - \frac{g^d}{y}\frac{y}{y^P}$$

$$\frac{c^*}{y^P} = \frac{c}{y^P} + \alpha_g\frac{y^G}{y}\frac{y}{y^P}$$

$$\varphi = \frac{1}{\left(\frac{L^P}{L^G}\right)\left(\frac{w^P}{w^G}\right)^{-\mu} + 1}$$

$$w = \left[(1-\varphi)\left(w^P\right)^{1+\mu} + \varphi\left(w^G\right)^{1+\mu}\right]^{\frac{1}{1+\mu}}$$

$$\frac{L}{y^P} = \left[\frac{\frac{L^P}{y^P}}{(1-\varphi)\left(\frac{w^P}{w}\right)^{\mu}}\right]$$

$$y^P = \left[\frac{\left(1-\tau^I\right)\left[(1-\theta e^{-\gamma})\left(\frac{c^*}{y^P}\right)\right]^{-\theta_L}(e^{-\gamma})^{1-\theta_L}w}{(1+\tau^C)(1+\eta^w)\left(\frac{L}{y^P}\right)^{\kappa}}\right]^{\frac{1}{\theta_L+\kappa}}$$

$$\frac{b}{y} = \frac{\frac{pfb}{y}}{\frac{R}{e^{\gamma}} - 1}$$

$$\frac{z}{y} = \left[\tau^I\left(w\frac{L}{y^P}\frac{y^P}{y} + r^K\frac{k}{L^P}\frac{L^P}{y^P}\frac{y^P}{y}\right) + \tau^C\frac{c}{y^P}\frac{y^P}{y} - \frac{g^d}{y} - \frac{w^G L^G}{y} - \left(Re^{-\gamma} - 1\right)\frac{b}{y}\right]$$

Given the solution to y^P, all other level steady state variables can be backed out using the steady state ratios.

A.3. **The Log-Linearized System.** We define the log deviations of a variable X from its steady state as $\hat{X}_t = \log X_t - \log X$. We define $\hat{a}_t \equiv a_t - \gamma$. Following Smets and Wouters (2007), we transform and normalize several shocks by setting $u_t^{b*} = \frac{(1-\rho_b)(e^\gamma - \theta)}{(e^\gamma + \theta)} u_t^b$, $u_t^{i*} = \frac{1}{(1+\beta)se^{2\gamma}} u_t^i$, $\hat{u}_t^p = \zeta_p \hat{\eta}_t^p$, $\hat{u}_t^w = \zeta_w \hat{\eta}_t^w$. We estimate processes for u_t^{b*}, u_t^{i*}, $\hat{u}_t^p$, and $\hat{u}_t^w$.

The equilibrium system in the log-linearized form consists of the following equations:

- Household FOC for consumption:

$$\hat{\lambda}_t = \hat{u}_t^b + \hat{u}_t^a - \frac{e^\gamma}{e^\gamma - \theta}(\hat{c}_t^* + \hat{u}_t^a) + \frac{\theta}{e^\gamma - \theta}\hat{c}_{t-1}^* - \frac{\tau^C}{1+\tau^C}\hat{\tau}_t^C \tag{A.34}$$

- Public/private consumption in utility:

$$\hat{c}_t^* = \frac{c}{c + \alpha_g y^g}\hat{c}_t + \frac{\alpha_g y^g}{c + \alpha_g y^g}\hat{y}_t^g \tag{A.35}$$

- Z^L process:

$$\hat{z}_t^L = \left(1 - \theta^L\right)\hat{z}_{t-1}^L - \left(1 - \theta^L - \frac{\theta^L \theta}{e^\gamma - \theta}\right)\hat{u}_t^a + \frac{\theta^L e^\gamma}{e^\gamma - \theta}\hat{c}_t^* - \frac{\theta^L \theta}{e^\gamma - \theta}\hat{c}_{t-1}^* \tag{A.36}$$

- Households' FOC for government bond:

$$\hat{\lambda}_t = \hat{R}_t + E_t\hat{\lambda}_{t+1} - E_t\hat{\pi}_{t+1} - E_t\hat{u}_{t+1}^a \tag{A.37}$$

- Households' FOC for investment:

$$(1+\beta)\,\hat{i}_t + \hat{a}_t - \frac{1}{se^{2\gamma}}[\hat{q}_t + \hat{u}_t^i] - \beta E_t\hat{i}_{t+1} - \beta E_t\hat{a}_{t+1} = \hat{i}_{t-1} \tag{A.38}$$

- Tobin's q:

$$\hat{q}_t + \hat{R}_t - E_t\hat{\pi}_{t+1} + \tau^I \beta e^{-\gamma} r^K E_t\hat{\tau}_{t+1}^I - \beta e^{-\gamma} r^K \left(1 - \tau^I\right) E_t\hat{r}_{t+1}^K - \beta e^{-\gamma}\left(1 - \delta\right) E_t\hat{q}_{t+1} = 0 \tag{A.39}$$

- Law of motion for capital:

$$\hat{\bar{k}}_t = (1-\delta)e^{-\gamma}(\hat{\bar{k}}_{t-1} - \hat{a}_t) + [1 - (1-\delta)e^{-\gamma}](\hat{u}_t^i + \hat{i}_t) \tag{A.40}$$

- Phillips curve:

$$\widehat{\pi}_t - \beta E_t\hat{\pi}_{t+1} - \zeta_p\left[\hat{m}c_t + \hat{\eta}_t^p\right] = 0 \tag{A.41}$$

  where $\zeta_p = \frac{1}{1+\eta^p \xi^p}\frac{(1-\beta\omega_p)(1-\omega_p)}{\omega_p}$ and ξ^p measures the curvature of the aggregator function: $\xi^p = 1 + \epsilon^p + \epsilon^p \frac{\mathbb{G}'''}{\mathbb{G}''}$.

- Wage rate:

$$\begin{aligned} &\hat{w}_t - \frac{\beta}{1+\beta}E_t\hat{w}_{t+1} + \zeta_w\left[\kappa\hat{u}_t - \hat{\eta}_t^w\right] \\ &+ \frac{1+\beta\chi^w}{1+\beta}\hat{\pi}_t - \frac{\beta}{1+\beta}E_t\hat{\pi}_{t+1} = \frac{1}{(1+\beta)}\hat{w}_{t-1} + \frac{\chi^w}{1+\beta}\hat{\pi}_{t-1} \\ &+ \frac{\chi^w}{1+\beta}\hat{a}_{t-1} - \frac{1+\beta\chi^w - \rho_a\beta}{1+\beta}\hat{a}_t \end{aligned} \tag{A.42}$$

where $\zeta_w \equiv \frac{1}{1+\eta^w\xi^w}\frac{(1-\beta\omega_w)(1-\omega_w)}{\omega_w(1+\beta)}$ and ξ^w measures the curvature of the labor aggregator function: $\xi^w = 1 + \epsilon^w + \epsilon^w \frac{\mathbb{G}_L'''}{\mathbb{G}_L''}$.

- Unemployment:

$$\kappa \hat{u}_t = \hat{w}_t - \hat{z}_t^L - \kappa \hat{L}_t - \frac{\tau^c}{1+\tau^c}\hat{\tau}_t^c - \frac{\tau^I}{1-\tau^I}\hat{\tau}_t^I - \hat{u}_t^L \tag{A.43}$$

- Capital-labor ratio:

$$\hat{r}_t^K - \hat{w}_t^P = \hat{L}_t^P - \hat{k}_t \tag{A.44}$$

- Production function:

$$\hat{y}_t^P = \frac{y^P + \Omega}{y^P}\left[\alpha(1-\nu)\hat{k}_t + (1-\alpha)(1-\nu)\hat{L}_t^P + \nu \hat{y}_t^G\right] \tag{A.45}$$

- Goods market equilibrium:

$$y^P \hat{y}_t^P - c\hat{c}_t - i\hat{i}_t - g^d \hat{g}_t^d - \psi'(1)k\hat{v}_t = 0 \tag{A.46}$$

- Government budget constraint:

$$\begin{aligned}&\frac{b}{y}\hat{b}_t - \frac{g^d}{Y}\hat{g}_t^d + \tau^I\left[\frac{r^K k}{y} + \frac{wL}{y}\right]\hat{\tau}_t^I + \tau^I\frac{r^K k}{y}\hat{r}_t^K + \tau^I\frac{r^K k}{y}\hat{k}_t + \tau^I\frac{wL}{y}\hat{w}_t + \tau^I\frac{wL}{y}\hat{L}_t - \frac{z}{y}\hat{z}_t \\ &+ \tau^C\frac{c}{y}\hat{\tau}_t^C + \tau^C\frac{c}{y}\hat{c}_t + \frac{R}{e^\gamma}\frac{b}{y}\hat{\pi}_t + \frac{R}{e^\gamma}\frac{b}{y}\hat{a}_t - \frac{w^G L^G}{y}\hat{w}_t^G - \frac{w^G L^G}{y}\hat{L}_t^G = \frac{R}{e^\gamma}\frac{b}{y}\hat{R}_{t-1} + \frac{R}{e^\gamma}\frac{b}{y}\hat{b}_{t-1}\end{aligned} \tag{A.47}$$

- Household's FOC for capital utilization:

$$\hat{r}_t^K - \frac{\tau^I}{1-\tau^I}\hat{\tau}_t^I - \frac{\psi''(1)}{\psi'(1)}\hat{v}_t = 0 \tag{A.48}$$

- Effective capital:

$$\hat{k}_t - \hat{v}_t - \hat{\bar{k}}_{t-1} + \hat{a}_t = 0 \tag{A.49}$$

- Marginal cost:

$$\hat{mc}_t - (1-\alpha)\hat{w}_t^P - \alpha\hat{r}_t^K + \frac{\nu}{1-\nu}\hat{y}_t^G - \frac{\nu}{1-\nu}\frac{y^P}{y^P+\Omega}\hat{y}_t^P = 0 \tag{A.50}$$

- Value added of government production:

$$\hat{y}_t^G - \hat{w}_t^G - \hat{L}_t^G = 0 \tag{A.51}$$

- Total output:

$$y\hat{y}_t - y^G\hat{y}_t^G - y^P\hat{y}_t^P = 0 \tag{A.52}$$

- Government output:

$$g\hat{g}_t - g^d\hat{g}_t^d - w^G L^G \hat{w}_t^G - w^G L^G \hat{L}_t^G = 0 \tag{A.53}$$

- Labor market equilibrium:

$$L^{\frac{1+\mu}{\mu}}\hat{L}_t - (1-\varphi)^{\frac{-1}{\mu}}\left(L^P\right)^{\frac{1+\mu}{\mu}}\hat{L}_t^P - \varphi^{\frac{-1}{\mu}}\left(L^G\right)^{\frac{1+\mu}{\mu}}\hat{L}_t^G = 0 \tag{A.54}$$

- Public sector labor:
$$\hat{L}_t^G - \mu\hat{w}_t^G + \mu\hat{w}_t - \hat{L}_t = 0 \tag{A.55}$$
- Aggregate wage index:
$$w^{1+\mu}\hat{w}_t - (1-\varphi)\left(w^P\right)^{1+\mu}\hat{w}_t^P - \varphi\left(w^G\right)^{1+\mu}\hat{w}_t^G = 0 \tag{A.56}$$
- Income tax rate:
$$\hat{\tau}_t^I = \rho_{\tau^I}\hat{\tau}_{t-1}^I + \gamma_{\tau^I}\hat{s}_{t-1}^b + \varepsilon_t^{\tau^I} \tag{A.57}$$
- Consumption tax rate:
$$\hat{\tau}_t^C = \rho_{\tau^C}\hat{\tau}_{t-1}^C + \gamma_{\tau^C}\hat{s}_{t-1}^b + \varepsilon_t^{\tau^C} \tag{A.58}$$
- Government goods purchase:
$$\hat{g}_t^d = \rho_g\hat{g}_{t-1}^d - \gamma_g\hat{s}_{t-1}^b + \varepsilon_t^g \tag{A.59}$$
- Public wage:
$$\hat{w}_t^g = \rho_{wg}\hat{w}_{t-1}^g + \kappa_{wp}\hat{w}_{t-1}^p - \gamma_{wg}\hat{s}_{t-1}^b + \varepsilon_t^{wg} \tag{A.60}$$
- Government transfer:
$$\hat{z}_t = \rho_z\hat{z}_{t-1} + \varepsilon_t^z \tag{A.61}$$

Appendix B. Data Description

Unless otherwise noted, the following raw data are taken from the National Income and Product Accounts (NIPA) Tables released by the Bureau of Economic Analysis.

- Consumption, $\mathsf{C_t}$, is defined as the sum of nominal personal consumption expenditures on nondurable goods (Table 1.1.5, line 5) and services (Table 1.1.5, line 6).
- Investment, $\mathsf{I_t}$, is defined as the sum of nominal personal consumption expenditures on durable goods (Table 1.1.5, line 4) and gross private domestic investment (Table 1.1.5, line 7).
- Income tax revenue, $\mathsf{T_t^I}$, is defined as the sum of nominal personal current taxes (NIPA Table 3.3 line 3), corporate income taxes (NIPA Table 3.3 line 10), and contributions for social insurance (NIPA Table 3.3 line 11) by S&L governments.
- Consumption tax revenue, $\mathsf{T_t^C}$, is defined as the nominal taxes on production and imports (NIPA Table 3.3 line 6) by S&L governments.
- Government goods purchase, $\mathsf{G^d}$, is defined as the sum of nominal government consumption expenditures and gross investment (NIPA Table 3.9.5 line 33), less compensation of general government employees (NIPA Table 3.10.5 line 50) by S&L governments.

- Government debt, B_t, is the credit market debt in nominal values outstanding by S&L governments, excluding employee retirement funds in the database of FRED Economic Data by Federal Reserve Bank of St. Louis. The series on municipal securities and loans (Tables F.211 and L.211 of Financial Accounts of the United States by the Federal Reserve Board) have been revised from 2004Q1 forward to reflect a change in data sources. To account for this change, which results in a jump in the S&L debt level of 2004Q1 by $771 billion, we use the growth rates of the original debt data from 1984 to 2003 and the debt level of the 2004Q1 to project backwards to approximate S&L debt levels between 1984 and 2003 under the revised data sources.
- Real private wage rate, $\tilde{w}_t^P$, is constructed from private compensation, scaled by the CPI and private hours worked. Private compensation is the sum of nominal wages and salaries (w&s) for private industries (NIPA Table 2.1 line 4) and supplements to w&s for private industries. Since supplements to w&s for private industries are not directly available among NIPA tables, we compute it by subtracting supplements to w&s of general government employees (the difference between compensation and w&s to general government employees, NIPA Table 3.10.5 line 4 and Table 2.1, line 5) from total supplements to w&s (NIPA Table 2.1 line 6). Private hours worked are computed as nonfarm business hours less hours worked by government enterprise employees and nonfarm unpaid family workers (BLS).
- Real public wage rate, $\tilde{w}_t^G$, is constructed from compensation of general government employees (NIPA Table 3.10.5, line 50), scaled by the CPI and hours worked for S&L governments. Hours worked for S&L governments hours are approximated by multiplying total government hours worked (BLS) with the share of S&L government employees to total government employees (BLS).
- Private employment, L_t^P, is defined as the index (2009Q3=100) for private-sector employment, constructed from as nonfarm business employees less employees of government enterprises and nonfarm proprietors (BLS).
- Inflation, π_t, is constructed using the index for the GDP price deflator (NIPA Table 1.1.4 line 1).
- The nominal interest rate, R_t, is defined as the federal funds rate from the Board of Governors of the Federal Reserve System. The quarterly data are constructed from the average of monthly effective rates and divided by 4.
- The unemployment rate, u_t, is defined as the number of unemployed divided by the labor force (BLS's Current Employment Statistics survey). The quarterly data are constructed from the average of monthly civilian unemployment rates.

The raw data of consumption, investment, income and consumption tax revenues, government goods purchase, and government debt are scaled by the GDP price deflator ($\mathsf{P_t}$) and the population index ($\mathsf{pop_t}$, constructed from civilian noninstitutional population, ages 16 and over, series ID LNS10000000, BLS), as

$$\mathsf{x}_t = 100 \times \ln(\frac{\mathsf{X}_t}{\mathsf{P_t} \times \mathsf{pop_t}}), \qquad \mathsf{x} \in \left\{\mathsf{c}, \mathsf{i}, \mathsf{t^I}, \mathsf{t^C}, \mathsf{g^d}, \mathsf{b}\right\}, \quad \mathsf{X} \in \left\{\mathsf{C}, \mathsf{I}, \mathsf{T^I}, \mathsf{T^C}, \mathsf{G^d}, \mathsf{B}\right\}.$$

The real wage rates are transformed as

$$\mathsf{w_t^P} = 100 \times \ln\left(\tilde{\mathsf{w}}_\mathsf{t}^\mathsf{P}\right) \qquad \text{and} \qquad \mathsf{w_t^G} = 100 \times \ln\left(\tilde{\mathsf{w}}_\mathsf{t}^\mathsf{G}\right).$$

The raw data of private employment are scaled by $\mathsf{pop_t}$ as

$$\mathsf{l_t^P} = 100 \times \ln\left(\frac{\mathsf{L_t^P}}{\mathsf{pop_t}}\right).$$

The GDP price deflator index is used to generate inflation as

$$\pi_t = 100 \times \ln\left(\frac{\mathsf{P_t}}{\mathsf{P_{t-1}}}\right).$$

Data for the observables and the log-linearized variables are linked by the following equations:

$$\begin{bmatrix} \mathsf{c_t} - \mathsf{c_{t-1}} \\ \mathsf{i_t} - \mathsf{i_{t-1}} \\ \mathsf{t_t} - \mathsf{t_{t-1}} \\ \mathsf{g_t^d} - \mathsf{g_{t-1}^d} \\ \mathsf{w_t^P} - \mathsf{w_{t-1}^P} \\ \mathsf{w_t^G} - \mathsf{w_{t-1}^G} \\ \mathsf{b_t} - \mathsf{b_{t-1}} \\ \mathsf{l_t^P} \\ \pi_\mathsf{t} \\ \mathsf{R_t} \\ \mathsf{u_t} \end{bmatrix} = \begin{bmatrix} 100\gamma \\ 100\gamma \\ 100\gamma \\ 100\gamma \\ 100\gamma \\ 100\gamma \\ 100\gamma \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} + 100 \times \begin{bmatrix} \hat{c}_t - \hat{c}_{t-1} + \hat{a}_t \\ \hat{i}_t - \hat{i}_{t-1} + \hat{a}_t \\ \hat{t}_t - \hat{t}_{t-1} + \hat{a}_t \\ \hat{g^d}_t - \hat{g^d}_{t-1} + \hat{a}_t \\ \hat{w^P}_t - \hat{w^P}_{t-1} + \hat{a}_t \\ \hat{w^G}_t - \hat{w^G}_{t-1} + \hat{a}_t \\ \hat{b}_t - \hat{b}_{t-1} + \hat{a}_t \\ \hat{L^P}_t \\ \hat{\pi}_t \\ \hat{R}_t \\ \hat{u}_t \end{bmatrix}. \tag{B.1}$$

Table 1. Calibrated parameters and Some Steady-State Values

Parameters	**Values**
β, discount factor	0.99
α, capital share	0.3
δ, quarterly depreciation rate for capital	0.025
η_w, steady-state markup in the labor market	0.14
η_p, steady-state markup in the good market	0.14
ξ^p, curvature of Kimball labor market aggregator	10
ξ^w, curvature of Kimball good market aggregator	10
$\frac{W^P}{W^G}$, private- to public-sector wages ratio	0.69
$\frac{W^G L^G}{Y}$, government compensation to output ratio	0.077
$\frac{G^d}{Y}$, government goods purchase to output ratio	0.045
$\frac{B}{4 \times Y}$, government debt to annual output ratio	0.12
$\frac{T^I}{Y}$, income tax revenue to output ratio	0.028
$\frac{T^C}{Y}$, cons. tax revenue to output ratio	0.108

Table 2. Prior and Posterior Estimates: the Baseline Model

Parameters	**Prior**			**Posterior**			
	func.	mean	std.	mode	mean	median	90% int
preference and technology							
100γ, steady state growth	N	0.5	0.03	0.47	0.48	0.48	(0.43, 0.52)
κ, inverse Frisch labor elast.	G	2	0.75	3.30	3.70	3.60	(2.70, 5.00)
θ, habit	B	0.5	0.2	0.86	0.84	0.85	(0.74, 0.92)
θ^L, wealth	B	0.5	0.2	0.02	0.02	0.02	(0.01, 0.04)
frictions							
ω_w, wage stickiness	B	0.5	0.1	0.16	0.18	0.18	(0.12, 0.26)
ω_p, price stickiness	B	0.5	0.1	0.76	0.76	0.76	(0.70, 0.83)
ψ, capital utilization	B	0.5	0.2	0.64	0.64	0.65	(0.34, 0.88)
s, investment adjustment cost	N	5	1.5	2.40	2.50	2.30	(1.50, 3.80)
χ_w, wage partial indexation	B	0.5	0.15	0.45	0.46	0.46	(0.28, 0.65)
μ, substitution elast. between sectors	G	3	1	1.40	1.50	1.50	(0.98, 2.10)
fiscal policy							
γ_g, govt goods purchase resp. to debt	N	0.2	0.03	0.039	0.041	0.041	(0.024, 0.06)
γ_{τ^I}, income tax resp. to debt	N	0.2	0.03	0.06	0.061	0.061	(0.03, 0.092)
γ_{τ^C}, consumption tax resp. to debt	N	0.2	0.03	0.02	0.02	0.02	(0.011, 0.03)
γ_{wg}, public wage resp. to debt	N	0.2	0.03	0.018	0.019	0.019	(-0.002, 0.042)
κ_{wp}, public wage elast. to private wage	N	0.5	0.2	0.21	0.23	0.22	(0.15, 0.31)
monetary policy							
ϕ_π, interest rate resp. to inflation	N	1.5	0.25	2.50	2.50	2.50	(2.20, 2.80)
ϕ_y, interest rate resp. to output	N	0.125	0.05	0.03	0.02	0.02	(0.00, 0.04)
ρ_r, lagged interest rate resp.	N	0.5	0.15	0.84	0.83	0.83	(0.80, 0.86)
serial correlation in disturbances							
ρ_a, technology	B	0.5	0.15	0.67	0.66	0.66	(0.56, 0.75)
ρ_b, preference	B	0.5	0.15	0.85	0.83	0.83	(0.74, 0.90)
ρ_i, investment	B	0.5	0.15	0.92	0.91	0.92	(0.88, 0.95)
ρ_L, labor supply	B	0.5	0.15	0.98	0.98	0.98	(0.96, 0.99)
ρ_w, wage markup	B	0.5	0.15	0.96	0.96	0.96	(0.93, 0.98)
ρ_p, price markup	B	0.5	0.15	0.95	0.94	0.95	(0.89, 0.97)
ρ_g, government goods purchase	B	0.5	0.15	0.97	0.97	0.97	(0.95, 0.98)
ρ_{τ^I}, income tax rate	B	0.5	0.15	0.88	0.87	0.87	(0.81, 0.93)
ρ_{τ^C}, consumption tax rate	B	0.5	0.15	0.95	0.95	0.95	(0.92, 0.97)
ρ_{wg}, public wage	B	0.5	0.15	0.85	0.84	0.84	(0.78, 0.90)
ρ_z, transfer	B	0.5	0.15	0.66	0.66	0.66	(0.56, 0.76)
θ_p, moving average in price markup	B	0.5	0.15	0.69	0.64	0.65	(0.49, 0.76)
θ_w, moving average in wage markup	B	0.5	0.15	0.07	0.09	0.08	(0.04, 0.16)
standard deviation of shocks							
σ_a, technology	IG^1	0.1	1	0.78	0.78	0.78	(0.70, 0.87)
σ_b, preference	IG	0.1	1	0.04	0.05	0.05	(0.03, 0.06)
σ_m, monetary policy	IG	0.1	1	0.13	0.14	0.14	(0.12, 0.16)
σ_i, investment	IG	0.1	1	0.38	0.40	0.39	(0.28, 0.53)
σ_L, labor supply	IG	0.1	1	1.90	2.10	2.10	(1.70, 2.70)
σ_w, wage markup	IG	0.1	1	1.00	1.00	1.00	(0.78, 1.40)
σ_p, price markup	IG	0.1	1	0.14	0.14	0.14	(0.11, 0.17)
σ_g, government goods purchase	IG	1	1	1.60	1.70	1.70	(1.50, 1.90)
σ_{τ^I}, income tax rate	IG	1	1	3.20	3.20	3.20	(2.90, 3.60)
σ_{τ^C}, consumption tax rate	IG	1	1	0.67	0.68	0.68	(0.62, 0.76)
σ_{wg}, public wage	IG	1	1	1.60	1.60	1.60	(1.40, 1.80)
σ_z, transfer	IG	1	1	1.70	1.80	1.80	(1.60, 2.00)

1: The inverse Gamma distribution is given by $f(x|s,\nu) = \nu^s \Gamma^{-1}(s) x^{-s-1} \exp^{\frac{-\nu}{x}}$.

TABLE 3. Present-Value, Cumulative Fiscal Multipliers: Mean and 90-percent Intervals (in Parentheses) for the Baseline Model

Variables	Impact	1 year	2 years	5 years
government compensation due to public wage shocks				
total output	0.97	0.82	0.66	0.39
	$(0.88, 1.06)$	$(0.68, 0.96)$	$(0.51, 0.81)$	$(0.19, 0.59)$
private output	-0.03	-0.18	-0.34	-0.61
	$(-0.12, 0.06)$	$(-0.32, -0.04)$	$(-0.49, -0.19)$	$(-0.81, -0.41)$
consumption	-0.01	-0.04	-0.05	-0.06
	$(-0.03, -0.00)$	$(-0.07, -0.01)$	$(-0.09, -0.01)$	$(-0.17, 0.06)$
investment	-0.08	-0.19	-0.27	-0.16
	$(-0.12, -0.04)$	$(-0.26, -0.11)$	$(-0.37, -0.18)$	$(-0.41, 0.08)$
government goods purchase				
total output	0.87	0.55	0.24	-0.35
	$(0.63, 1.10)$	$(0.28, 0.82)$	$(0.01, 0.48)$	$(-0.57, -0.14)$
private output	0.97	0.57	0.23	-0.05
	$(0.72, 1.22)$	$(0.28, 0.86)$	$(0.01, 0.47)$	$(-0.40, 0.33)$
consumption	-0.09	-0.21	-0.31	-0.53
	$(-0.15, -0.04)$	$(-0.32, -0.11)$	$(-0.42, -0.20)$	$(-0.63, -0.43)$
investment	-0.18	-0.40	-0.57	-0.63
	$(-0.23, -0.13)$	$(-0.49, -0.31)$	$(-0.68, -0.45)$	$(-0.91, -0.30)$

Table 4. Posterior Estimation: Sensitivity Analysis

specifications		1	2	3
	priors	baseline	$\alpha_G > 0$	$\nu > 0$
preference and technology				
100γ	N(0.5, 0.03)	0.48	0.48	0.48
κ	G(2, 0.75)	3.70	3.70	3.70
θ	B(0.5, 0.2)	0.84	0.84	0.83
θ^L	B(0.5, 0.2)	0.02	0.02	0.03
α_G	U(0, 0.866)	–	-0.00	–
ν	G(0.05, 0.02)	–	–	0.008
frictions				
ω_w	B(0.5, 0.1)	0.18	0.19	0.19
ω_p	B(0.5, 0.1)	0.76	0.76	0.75
ψ	B(0.5, 0.2)	0.64	0.64	0.66
s	N(5, 1.5)	2.50	2.40	2.30
χ_w	B(0.5, 0.15)	0.46	0.46	0.46
μ	G(3, 1)	1.50	1.40	1.30
fiscal policy				
γ_g	N(0.2, 0.03)	0.041	0.041	0.04
γ_{τ^I}	N(0.2, 0.03)	0.061	0.061	0.061
γ_{τ^C}	N(0.2, 0.03)	0.02	0.02	0.02
γ_{wg}	N(0.2, 0.03)	0.019	0.019	0.019
κ_{wp}	N(0.5, 0.2)	0.23	0.22	0.23
monetary policy				
ϕ_π	N(1.5, 0.25)	2.50	2.50	2.50
ϕ_y	N(0.125, 0.05)	0.02	0.02	0.02
ρ_r	B(0.5, 0.15)	0.83	0.83	0.83
serial correlation in disturbances				
ρ_a	B(0.5, 0.15)	0.66	0.65	0.64
ρ_b	B(0.5, 0.15)	0.83	0.83	0.84
ρ_i	B(0.5, 0.15)	0.91	0.91	0.92
ρ_L	B(0.5, 0.15)	0.98	0.98	0.98
ρ_w	B(0.5, 0.15)	0.96	0.96	0.96
ρ_p	B(0.5, 0.15)	0.94	0.94	0.95
ρ_g	B(0.5, 0.15)	0.97	0.97	0.97
ρ_{τ^I}	B(0.5, 0.15)	0.87	0.87	0.87
ρ_{τ^C}	B(0.5, 0.15)	0.95	0.95	0.95
ρ_{wg}	B(0.5, 0.15)	0.84	0.84	0.84
ρ_z	B(0.5, 0.15)	0.66	0.66	0.65
θ_p	B(0.5, 0.15)	0.64	0.63	0.64
θ_w	B(0.5, 0.15)	0.09	0.09	0.09
standard deviation of shocks				
σ_a	$IG(0.1, 1)$	0.78	0.78	0.79
σ_b	$IG(0.1, 1)$	0.05	0.05	0.04
σ_m	$IG(0.1, 1)$	0.14	0.14	0.14
σ_i	$IG(0.1, 1)$	0.40	0.40	0.42
σ_L	$IG(0.1, 1)$	2.10	2.10	2.10
σ_w	$IG(0.1, 1)$	1.00	1.00	1.00
σ_p	$IG(0.1, 1)$	0.14	0.14	0.15
σ_g	$IG(1, 1)$	1.70	1.70	1.70
σ_{τ^I}	$IG(1, 1)$	3.20	3.20	3.20
σ_{τ^C}	$IG(1, 1)$	0.68	0.68	0.68
σ_{wg}	$IG(1, 1)$	1.60	1.60	1.60
σ_z	$IG(1, 1)$	1.80	1.80	1.80

The point estimates under each specification column is the mean of posterior distributions.

Table 5. Model Fit Comparison

specifications	log marginal data density	Bayes factor to baseline
1. baseline	−2020	1
2. $\alpha_G > 0$	−2022.8	$e^{2.8}$
3. $\nu > 0$	−2030.7	$e^{10.7}$

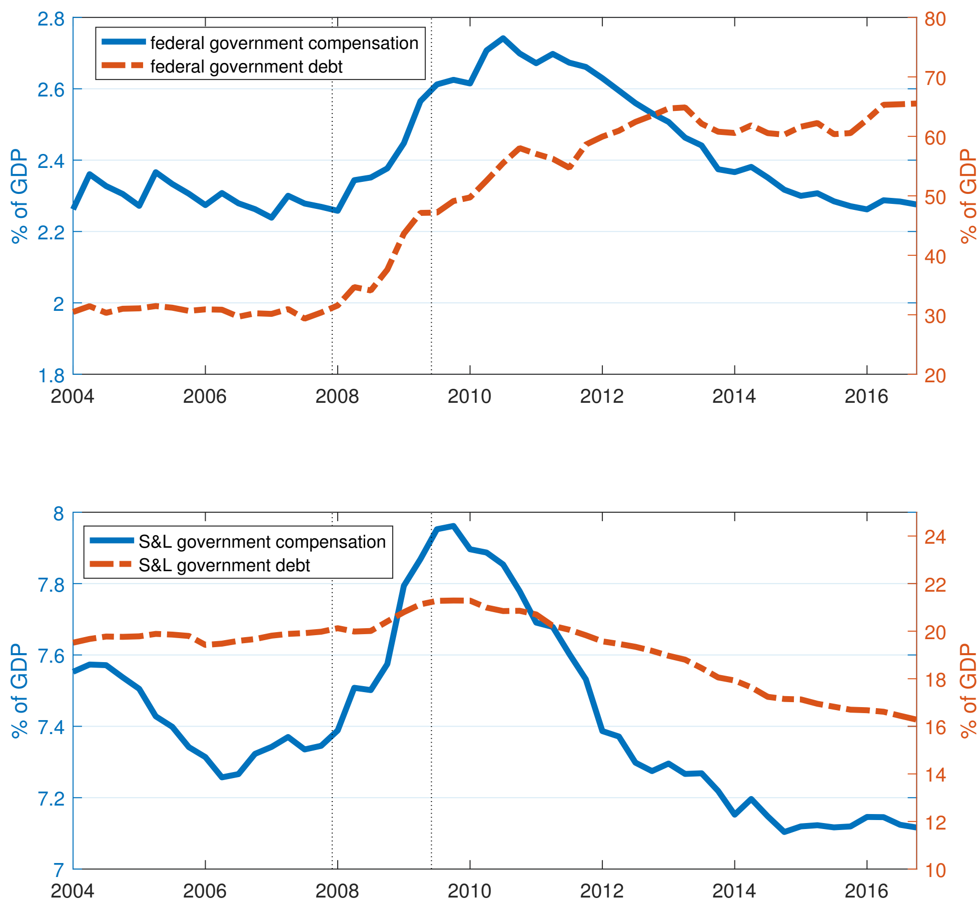

Figure 1. **U.S. government debt vs. compensation.** Government compensation to GDP shares are the nominal compensation of general government employees of the federal government and S&L governments (NIPA Table 3.10.5, lines 15 and 50), divided by nominal GDP (NIPA Table 1.1.5, line 1). See Appendix B for the description of government debt. The vertical dotted lines encompass the Great Recession period.

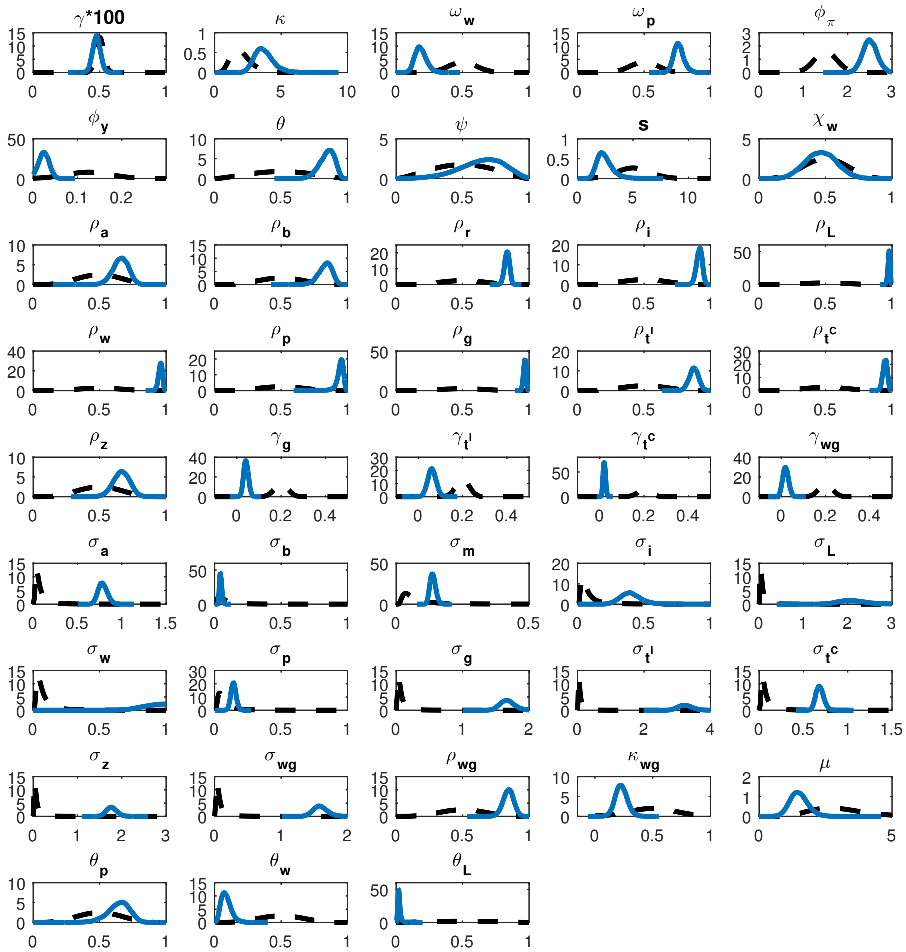

FIGURE 2. Prior vs. posterior distributions: the baseline model.

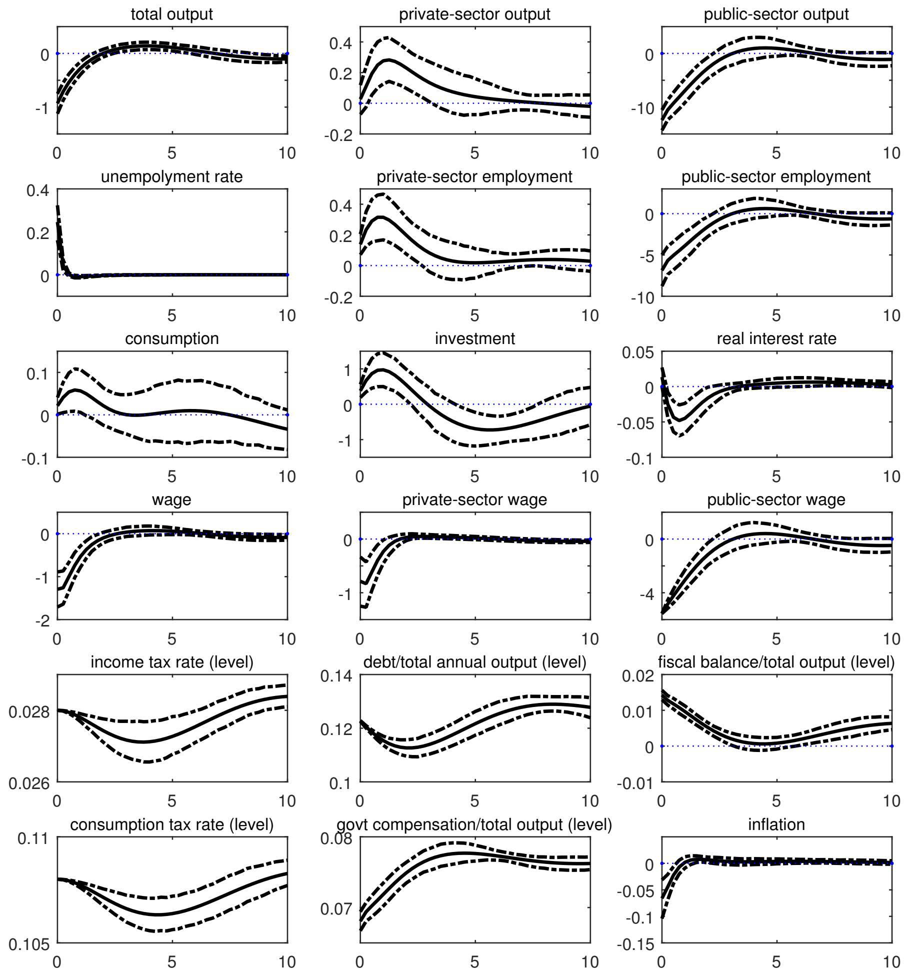

FIGURE 3. Effects of a public wage reduction: the baseline model. The shock size of ε_t^{wg} leads to a government compensation decrease of 1 percentage point of the steady-state output. X-axis is in years; y-axis is in percent deviation from the steady state unless otherwise specified.

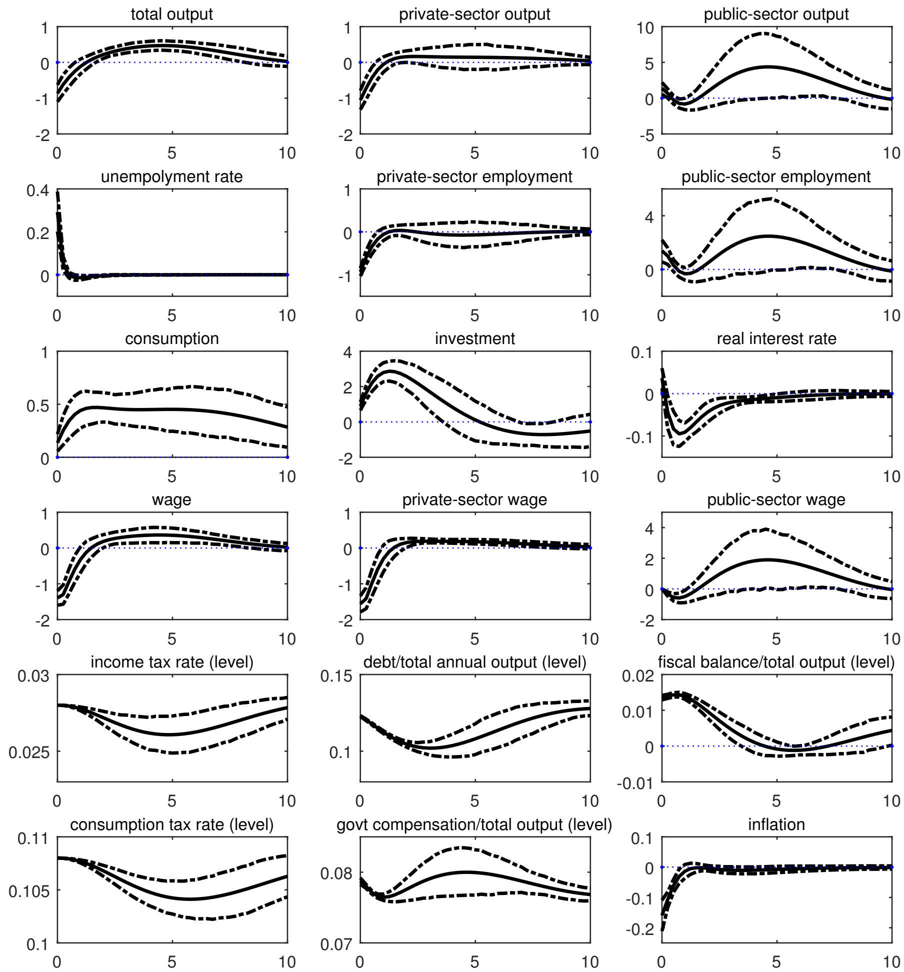

FIGURE 4. Effects of a government goods purchase reduction: the baseline model. The shock size of ε_t^{gd} leads to a government goods purchase decrease of 1 percentage point of the steady-state output. X-axis is in years; y-axis is in percent deviation from the steady state unless otherwise specified.

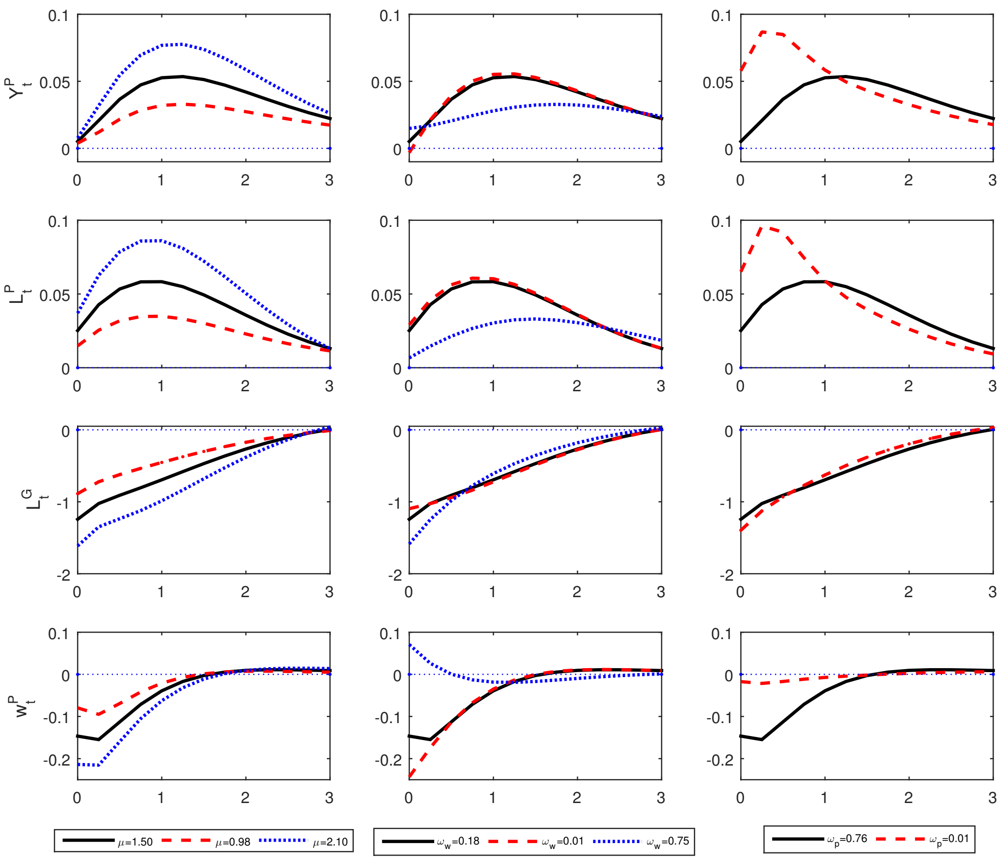

FIGURE 5. Public and private wage interactions: different degrees of nominal wage and price rigidities and the elasticity of substitutability between public- and private-sector output, labor, and wage. The responses are in percent deviation from the steady-state levels to a -1% shock in the public wage rate. X-axis is in years.

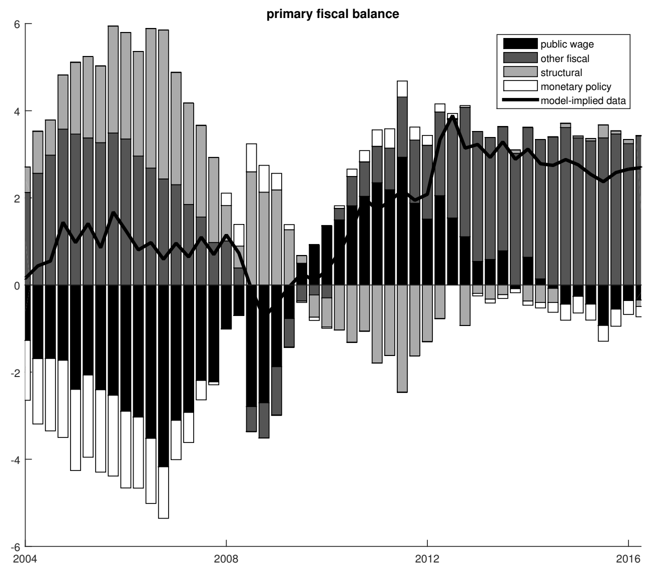

FIGURE 6. Historical decomposition of primary fiscal balance. Structural shocks are the aggregate of all non-policy shocks. Units for the y-axis are percentage deviation from the steady-state path.

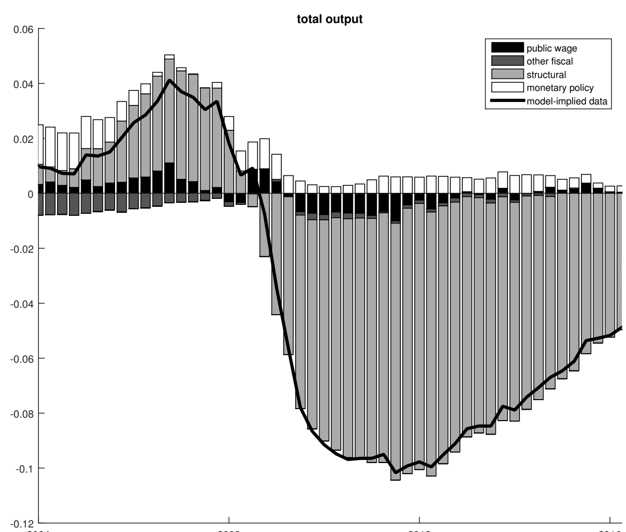

FIGURE 7. Historical decomposition of output. Structural shocks are the aggregate of all non-policy shocks. Units for the y-axis are percentage deviation from the steady-state path.

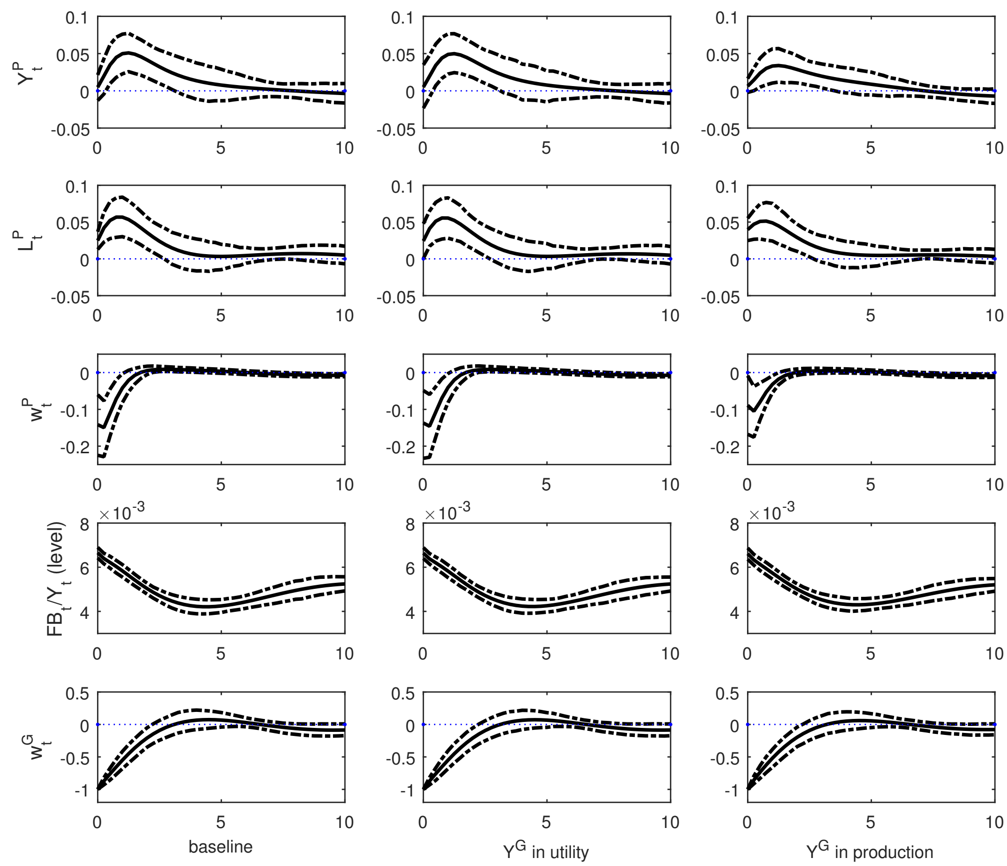

FIGURE 8. Sensitivity analysis of impulse responses of -1% public wage shock. Each column denotes an alternative estimation specification. Solid lines denote the posterior mean responses and dotted-dashed lines are the 90-percent intervals from the posterior distributions. X-axis is in years; y-axis is in percent deviation from the steady state unless specified otherwise.

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