State dependent government spending multipliers: Downward nominal wage rigidity and sources of business cycle fluctuations[*]

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Abstract

This paper shows that the source of business cycle fluctuations matters for determining the size of government spending multipliers. We present a New Keynesian model with downward nominal wage rigidity (DNWR) and show that government spending is much more effective in stimulating output in a demand shock driven recession compared to a supply shock driven recession. Government spending multiplier is large when DNWR binds in a recession, but the nature of recession matters due to the opposing responses of inflation depending on the type of recession. In a demand-driven recession, inflation falls, preventing real wages from falling, leading to consequences for employment, while inflation rises in a supply-driven recession limiting the consequences of DNWR on employment. We document supporting empirical evidence, using both historical time series data and cross-sectional data from U.S. states, that the government spending multiplier for output is larger in a demand-driven recession compared to a supply-driven recession.

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1 Introduction

The recent period of low interest rates have shown that fiscal policies have become crucial for economic recovery. Thus, understanding the effects of increased government spending for the economy is of utmost importance, particularly for policymakers. This information is summarized in terms of multipliers, that quantify the rise in output as a result of a $1 increase in government spending. Recently, the literature has made great strides in going beyond the average effects of government spending, and distinguishing these effects based on the state of the underlying economy. Empirical research on the state-dependence of fiscal multiplier is an active area of research, with a lack of consensus on the relative state dependencies in the effectiveness of government spending across good and bad times.[1] Moreover, our understanding of the fiscal transmission at play across different states of the economy is relatively limited.

This paper contributes to both the empirical and theoretical literature on the state-dependence of government spending and establishes that the source of business cycle fluctuations matter. In particular, the government spending multiplier is different across recessions, based on whether they are supply or demand driven.

We propose a New Keynesian model featuring downward nominal wage rigidity (DNWR) with two different sources of the business cycle shocks: demand and supply shocks.[2] In an expansion, the usual effects of government spending prevail in the model, with consumption being crowded out due to negative wealth effects and rising real interest rate due to higher inflation. The DNWR constraint becomes relevant during a recession. Nominal wages being rigid downwards means that in a recession, nominal wages cannot fall and can be possibly higher than the optimal wage, leading to an increase in unemployment. In a demand-driven recession, inflation falls and thus DNWR prevents real wages from falling. As nominal wages are higher than the optimal level, expansionary fiscal policy does not increase nominal wages or marginal cost of production immediately in a recession. Thus, it does not lead to a rise in inflation and subsequently the real interest rate. As a consequence, it leads to less crowding-out effects and bigger government spending multiplier than in an expansion. On the other hand, in a supply-driven recession, inflation goes up, and thus even if the DNWR constraint binds, it has a limited impact on real wages. As a result, increased government spending is less effective in a

[1]See for example, Auerbach and Gorodnichenko (2012), Nakamura and Steinsson (2014) and Ramey and Zubairy (2018).

[2]The presence of DNWR in the US is well documented, for example, Card and Hyslop (1996); Kahn (1997); Lebow, Sacks, and Anne (2003); Barattieri, Basu, and Gottschalk (2014); Daly and Hobijn (2014); Fallick, Lettau, and Wascher (2016); Kurmann and McEntarfer (2018); Grigsby, Hurst, and Yildirmaz (2019); Hazell and Taska (2020); Murray (2019)

supply driven recession.

We first solve the model analytically to highlight the mechanism which gives rise to a higher spending multiplier when DNWR binds. This analytical model also helps us illustrate that in addition to the source of fluctuations, the size and sign of government spending might also affect the resulting multiplier. In our quantitative model, when we simulate a deep recession to match the trough of the Great Recession, the government spending multiplier is 1.7 in a demand-driven recession, and 0.54 in a supply-driven recession and expansion, since DNWR does not bind in a supply driven recession or expansion.

Next we provide empirical evidence to support these findings. We first focus on time series evidence based on historical macroeconomic data for United States, following Ramey and Zubairy (2018). This long time series data spanning 1889 to 2015 helps us to exploit time variation in government spending, and also allows us to distinguish between periods of high unemployment accompanied with high and low inflation historically. We find evidence that government spending multiplier is statistically significant larger in a high unemployment period accompanied with low inflation, classified as a demand-driven recession, than a high unemployment period accompanied with high inflation, i.e. a supply-driven recession. This finding is robust to considering military spending news alone or jointly with innovations identified following Blanchard and Perotti (2002) in order to identify spending shocks.

We also conduct a regional analysis, exploiting variation in military procurement contracts across U.S. states in the spirit of Nakamura and Steinsson (2014) to provide further empirical support for our findings for the sample period 1966 to 2018. The U.S. state-level analysis helps to capture a relative or local multiplier, since the time fixed effects control for any aggregate general equilibrium effects, such as the response of monetary policy or taxes and financing response to changes in government spending. We find that the effects of government spending on the economy are larger in periods when the employment rate is low, and particularly when it coincides with low inflation. Notably, this regional approach also allows us to exploit a new data set quantifying a DNWR measure across U.S. states from Jo (2020) to test our proposed mechanism directly. We find larger effects of government spending when low employment coincides with states facing higher level of DNWR, and low inflation, conditions that would satisfy a demand-driven recession in our theoretical setting.

The paper has four major contributions. In our theoretical model, we rely on downward nominal wage rigidity (DNWR) as a key mechanism. In a model with DNWR, what happens to real wages is of primary importance in driving unemployment in the model.

We firstly show that the difference in the response of inflation across demand and supply shocks leads to different consequences for real wages even if the nominal wages are downwardly bound across the two cases. Thus, the frictions in real wages transmitted by the joint behavior of nominal wages and inflation are at the heart of exploiting DNWR as a way to generate asymmetries in the business cycle.[3]

Second, as a consequence of these findings, we show that the source of fluctuation matters for the size of the fiscal multiplier, particularly in a recession. The distinction between good and bad times alone might not be sufficient when considering state-dependent government spending multiplier and the shocks driving the recession constitute an important factor. Notably, the same increase in government spending will have a larger output multiplier if the recession is driven by demand shocks and there is a co-movement of output and inflation, versus one where the recession is driven by supply shocks and output and inflation move in opposing directions.

Some well-established methodologies that have considered state dependence of government spending multipliers exploiting historical time series or cross-sectional data have found limited evidence of larger multipliers across periods of slack in the economy. Our third contribution is to exploit rich historical data to show that these same estimation strategies yield statistically significantly larger multipliers in periods of slack accompanied with low inflation than with high inflation, using our theoretical results to distinguish between demand and supply driven recessions, respectively. This also potentially helps to reconcile some disagreement on the relative size of spending multipliers in recessions versus expansion, depending on choice of dataset with differing nature of recessions.

Lastly, our cross-sectional analysis employing U.S. state-level data also allows us to test the mechanism from our theoretical model directly, as we use a new data set quantifying a DNWR measure across U.S. states over time. We show that the local spending multiplier is higher in a demand-driven recession with a high degree of DNWR than in a supply-driven recession, which is consistent with our theoretical predictions.

1.1 Related Literature

Our model contributes to the small but growing literature on theoretical explanations behind variations in the size of government spending multipliers based on the state of

[3] Benigno and Ricci (2011); Schmitt-Grohé and Uribe (2016, 2017); Dupraz, Nakamura, and Steinsson (2019)

the economy.[4] Shen and Yang (2018) show in a New Keynesian model that government spending multipliers can be higher in a recession than in a boom when there are downward nominal wage rigidity constraints. Michaillat (2014) generates countercyclical multipliers of government spending in a search and matching model, focusing on public employment. During high unemployment periods the rise in public employment increases labor market tightness to a small degree and also has a smaller crowding out effect on private employment. Albertini, Auray, Bouakez, and Eyquem (2020) consider a model with involuntary unemployment, incomplete markets and nominal rigidities. They are able to generate state dependent government multipliers as increased spending reduces unemployment and thus unemployment risk and precautionary savings to a greater extent during high unemployment periods. In departure from this literature, we further distinguish between the nature of recession and establish that the driving force of the business cycle plays a crucial role in the magnitude of the multiplier during a period of high unemployment.

The closest paper to our analysis is Ghassibe and Zanetti (2020) that also presents a model of differential fiscal multiplier depending upon the source of shock.[5] Their model features search and matching frictions in a goods market and goods market tightness increases in a demand boom, and decreases in a supply boom. The demand side fiscal multiplier is countercyclical under demand-side fluctuations since the crowding-out effect is stronger when the market is tighter. They provide empirical support for their findings by estimating spending and tax cut multipliers in recessionary and expansionary episodes, conditional on those being either demand- or supply-driven, by distinguishing between the comovement between economic activity and inflation. However, we differ in the main friction of the model - our study examines a nominal friction, DNWR. We also present empirical findings in line with theoretical results on unemployment,inflation, and DNWR.

Downward nominal wage rigidity have been explored as a way to generate asymmetric multipliers, considering differences in response to expansionary versus contrac-

[4] A larger strand of the theoretical literature has considered how the stance of monetary policy affects government spending multiplier. Notably, they show in a New Keynesian model, spending multipliers are much larger at the ZLB than in normal times. See for example, Christiano et al. (2011), Woodford (2011) and Eggertsson (2011). Somewhat related to our work on distinguishing between sources of fluctuations, Mertens and Ravn (2014) find that the size of the fiscal multiplier depends on the type of shock that pushed the economy into the liquidity trap. In particular, they show that when the liquidity trap is due to a non-fundamental shock, supply- side fiscal instruments have a large multiplier, and demand- side fiscal instruments have a small multiplier. The reverse is true when the liquidity trap is caused by a fundamental shock.

[5] Notably, they find that policies stimulating aggregate demand, like increased government spending is more effective in demand driven recessions relative to supply driven recessions. On the other hand policies affecting aggregate supply have larger multipliers in supply-driven recession than demand riven recession.

tionary government spending beyond the state of the economy. Barnichon, Debortoli, and Matthes (2020) consider a model with incomplete markets and DNWR and generate asymmetric and state-dependent effects of government spending multipliers. In a small open economy model with DNWR, Born, D'Ascanio, Müller, and Pfeifer (2019) show that the real exchange rate and output respond asymmetrically to negative and positive government spending shocks under a peg, and support this with empirical findings. Our work differs in further emphasizing the role of the source of fluctuation in characterizing state-dependent government spending multipliers.[6]

Our paper also contributes to the large empirical literature on state-dependent fiscal policy, notably one that explores whether the government spending multiplier differs based on the state of the economy. Some notable studies like Auerbach and Gorodnichenko (2012) and Auerbach and Gorodnichenko (2013) find notably larger spending multipliers in recessions than in expansions. Ramey and Zubairy (2018) on the other hand do not find multipliers larger than 1 in any state of the economy, and limited evidence of significantly larger multipliers during periods of slack. We extend this analysis to show that conditioning on the source of fluctuation is important and find evidence of spending multipliers close to 1 in a demand driven recession, which is statistically significantly larger than multipliers in expansions and supply-driven recessions.

Defense contracts have been used to identify cross-sectional local multipliers by many others[7] since Nakamura and Steinsson (2014). However, the focus has been on quantifying local multipliers, their spillovers effects and potentially the mapping to the aggregate multiplier. See Chodorow-Reich (2019) for a survey of this local multiplier literature that exploits state-level variation. Bernardini, De Schryder, and Peersman (2020) use U.S. state level data to study the effects of fiscal policy in the decade surrounding Great Recession, and find larger multipliers when a state is in a recession or had a high level of household indebtedness. Our paper uses US states-year panel data to identify state-dependent local multipliers depending upon the source of the business cycle. We further exploit US state-level degree of DNWR to suggest empirical findings consistent with our model results, namely that the local multiplier is higher in a US state with a high degree of DNWR in a low inflation recession.

The remainder of the paper is organized as follows. Section 2 introduces a New Keynesian model with DNWR. We examine analytical solution in Section 3. Section 4 presents quantitative results in spending multipliers depending on the state of the economy and

[6] In our analytical and quantitative model, we also briefly touch upon how the sign of government spending affects the size of spending multiplier based on the state of the economy and nature of recession.

[7] Dupor and Guerrero (2017), Auerbach, Gorodnichenko, and Murphy (2019), Demyanyk, Loutskina, and Murphy (2019), and Auerbach, Gorodnichenko, and Murphy (2020), among others.

source of fluctuation. Section 5 and Section 6 provide empirical evidence of our proposed model with historical time series data and US state-level annual panel data, respectively. Section 7 concludes.

2 New Keynesian model featuring DNWR

Our baseline model is a New Keynesian model with government spending subject to a DNWR constraint, featuring two sources of the business cycle. Shen and Yang (2018) introduce a DNWR constraint into the New Keynesian model with government spending with a preference shocks driven business cycle. We extend this model to allow for productivity shocks, and study the role of the sources of business cycle fluctuations in determining government spending multipliers particularly when the DNWR constraint binds.

2.1 Households

A representative households chooses consumption c_t, labor n_t, and nominal bonds B_t to maximize utility over an infinite time horizon:

$$\max \sum_{t=0}^{\infty} \prod_{j=1}^{t} \beta_j \frac{[c_t - \chi(n_t)^{\varphi}]^{1-\sigma}}{1-\sigma},$$

where β_j is the time varying discount factor in period j. σ is the inverse of the intertemporal elasticity of substitution and $\frac{1}{\varphi-1}$ is the Frisch elasticity of labor supply. We consider GHH (Greenwood, Hercowitz, and Huffman (1988)) preferences that imply no wealth effect on labor supply.[8] There are a continuum of consumption goods $c_t(i)$ where $i \in [0,1]$. The composite consumption is aggregated with the Dixit and Stiglitz (1977) aggregator, $c_t = \left(\int_0^1 c_t(i)^{\frac{\theta-1}{\theta}} di\right)^{\frac{\theta}{\theta-1}}$. Households are subject to the following period t budget constraint,

$$P_t c_t + B_t + T_t = W_t n_t + R_{t-1} B_{t-1} + \int_0^1 \Gamma(i) di,$$

where P_t is the aggregate price index, B_t is nominal bond, T_t is lump-sum tax, W_t is the nominal wage rate, and R_{t-1} is the nominal interest rate between $t-1$ and t, and $\Gamma(i)$ is the profit from ownership of firm i.

[8] These preferences are commonly used in the DNWR literature and simplify the analytical analysis that follows. We have conducted the quantitative analysis with King, Plosser, and Rebelo (1988) preferences, that allow for a wealth effect on labor supply, also. Our main findings follow through and the results are shown in in Table A.1 in Appendix A.2.

We assume that nominal wage adjustment is constrained downwardly, as proposed by Schmitt-Grohé and Uribe (2016).

$$W_t \geq \gamma W_{t-1}, \qquad \gamma > 0. \tag{1}$$

The parameter γ governs the degree of DNWR. Nominal wages cannot fall below the previous period's wage when γ is greater than one, while nominal wages are fully flexible when γ is zero. If we assume $\gamma > 0$, nominal wages are not fully flexible and the labor market does not clear all the time. Actual employment used for production (n_t) can be lower than labor supply (n_t^s) when a shock drives the DNWR constraint to bind. Nominal wages and employment must satisfy the complementary slackness condition:

$$(n_t^s - n_t)(W_t - \gamma W_{t-1}) = 0. \tag{2}$$

When DNWR constraint is not binding $(W_t > \gamma W_{t-1})$,the labor market clears $(n_t^s = n_t)$ and unemployment rate is zero. When DNWR constraint is binding, there is involuntary unemployment $(n_t < n_t^s)$, as the households' willingness to work at the prevailing wage is larger than labor demand. We define the unemployment rate as,

$$u_t = \frac{n_t^s - n_t}{n_t^s} \times 100.$$

2.2 Firms

The final good y_t is produced with a continuum of intermediate goods, $y_t(i)$, $i \in [0, 1]$, with the technology:

$$y_t = \left(\int_0^1 y_t(i)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}}.$$

Firms in this market operate under perfectly competitive conditions. Profits are given by

$$P_t y_t - \int_0^1 p_t(i) y_t(i) di.$$

Firms maximize profits subject to the above production technology. The implied demand functions for intermediate goods are $y_t(i) = \left(\frac{p_t(i)}{P_t}\right)^{-\theta} y_t$. Perfect competition drives profits to zero. As a consequence, the price level is given by $P_t = \left[\int_0^1 p_t(i)^{1-\theta} di\right]^{\frac{1}{1-\theta}}$.

Intermediate good i is produced using labor:

$$y_t(i) = A_t n_t(i), \tag{3}$$

where A_t represents for the technology. Given the output level $y_t(i)$ chosen in period t, cost minimization implies marginal cost as given by,

$$mc_t(i) = \frac{w_t}{A_t}.$$

Following Calvo (1983), a fraction $1-\omega$ of intermediate firms can optimally choose their prices each period. Firms which get a chance to reset their prices in period t choose their price to maximize the expected sum of discounted future profits. Suppose firm i has the chance to adjust the price in period t. Let $P_t^*(i)$ be the chosen price. Then, $P_t^*(i)$ is set so as to maximize

$$\max_{P_t^*(i)} \mathbb{E}_t \sum_{j=0}^{\infty} \omega^j \lambda_{t,t+j} y_{t,t+j}(i) [\frac{P_t(i)^*}{P_{t+j}} - mc_{t+j}(i)]$$

subject to demand for intermediate goods:

$$y_{t,t+j}(i) = \left(\frac{P_t^*(i)}{P_{t+j}}\right)^{-\theta} y_{t+j},$$

where $\lambda_{t,t+j} = \mathbb{E}_t \prod_{k=1}^{j} \beta_{t+k} \frac{\lambda_{t+j}}{\lambda_t}$ is the stochastic discount factor for real j-period ahead profit.

As all firms adjusting prices in period t set the same price, or $P_t^*(i) = P_t^*(j)$, we can then write the price level as

$$1 = (1-\omega) p_t^{*1-\theta} + \omega \pi_t^{\theta-1},$$

where $\pi_t \equiv P_t/P_{t-1}$ denotes the gross rate of inflation between $t-1$ and t and $p_t^* \equiv P_t^*/P_t$ denotes the relative price of the varieties whose price are adjusted in t relative to the final good.

Combining the market clearing condition for each $y_t(i)$ and the production function yields

$$y_t(i) = A_t n_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\theta} y_t.$$

Aggregating over labor leads to,

$$y_t = A_t \frac{n_t}{s_t},$$

where $s_t \equiv \int_0^1 (\frac{P_{it}}{P_t})^{-\frac{\theta}{1-\alpha}} di$ measures the price dispersion.[9]

[9]The full set of optimizing conditions characterizing the equilibrium are shown in the Appendix A.1.

2.3 Fiscal and monetary policy

Monetary policy follows the Taylor rule, and the gross nominal interest rate R_t responds to the deviations of the inflation rate from its steady state, which is summarized as

$$R_t = R(\frac{\pi_t}{\pi})^{\alpha_\pi},$$

where π denotes the steady-state level of inflation. The government collects lump-sum tax T_t to balance the government budget constraint each period:

$$g_t = \frac{T_t}{P_t}.$$

The aggregate market clearing condition is

$$y_t = c_t + g_t.$$

3 Analytics of state-dependent government spending multipliers

In this section, we solve the model analytically to describe the main mechanisms at play in the model. These analytical results help illustrate how government spending multipliers depend on the state of the economy and how they rely on the source of business cycle fluctuations. For tractability, we assume that $\gamma = 1$, i.e. absolute DNWR, which means that nominal wages can not adjust downward. We consider a one-time government spending shock ($\widehat{g}_t$=$\widehat{g}_t$ and $\mathbb{E}_t\widehat{g}_{t+1}$=0).

We log-linearize the equilibrium conditions and summarize them into two equations: the IS curve (Equation (4)) and the Phillips curve (Equation (5) or Equation (6)). The model has two equilibria depending on the labor market output: full-employment and slack. The marginal costs depend on the level of current production at the full-employment equilibrium, and are a function of the previous period wage when DNWR binds and the economy suffers from involuntary unemployment. Each equilibrium is associated with a different Phillips curve (PC) while the IS curve stays the same. The IS curve can be written as

$$\widehat{y}_t = \mathbb{E}_t\widehat{y}_{t+1} - (\theta - 1)(\widehat{a}_t - \mathbb{E}_t\widehat{a}_{t+1}) + \theta s_g(\widehat{g}_t - \mathbb{E}_t\widehat{g}_{t+1}) - \Psi(\alpha_\pi\widehat{\pi}_t - \mathbb{E}_t\widehat{\pi}_{t+1}) - \Psi\mathbb{E}_t\widehat{\beta}_{t+1}, \quad (4)$$

where hat variables stand for log-deviations from the steady state and $\Psi = \frac{\theta\varphi(1-s_g)-\theta+1}{\sigma\varphi}$. s_g is the steady state government spending to GDP ratio. When DNWR constraint does not bind, or in the full employment equilibrium, the PC is

$$\widehat{\pi}_t = \frac{(1-\omega)(1-\omega\beta)}{\omega}(\varphi-1)\widehat{y}_t - \frac{(1-\omega)(1-\omega\beta)}{\omega}\varphi\widehat{a}_t + \beta\mathbb{E}_t\widehat{\pi}_{t+1}. \tag{5}$$

In contrast, when DNWR constraint binds, or in the slack equilibrium, the PC becomes

$$\widehat{\pi}_t = \frac{(1-\omega)(1-\omega\beta)}{\omega+(1-\omega)(1-\omega\beta)}[\widehat{w}_{t-1} - \widehat{a}_t] + \frac{\omega\beta}{\omega+(1-\omega)(1-\omega\beta)}\mathbb{E}_t\widehat{\pi}_{t+1}. \tag{6}$$

Detailed derivations of log approximation of the equilibrium conditions are available in Appendix A.1.1. Now let's consider the business cycles from two sources of shocks - a preference shock ($\widehat{\beta}_{t+1}$) and a productivity shock ($\widehat{a}_t$).

Assumption 1. The sequences of the preference shock ($\mathbb{E}_t\widehat{\beta}_{t+1} = b_L$ and $\mathbb{E}_t\widehat{\beta}_{t+2} = 0$) and ($\mathbb{E}_t\widehat{\beta}_{t+1} = b_H$ and $\mathbb{E}_t\widehat{\beta}_{t+2} = 0$) cause a demand-driven expansion and recession, respectively, in period t. The sequence of the technology shock ($\widehat{a}_t{=}a_H$, $\mathbb{E}_t\widehat{a}_{t+1}{=}\rho_a a_H$, and $\mathbb{E}_t\widehat{a}_{t+2}{=}a_L$) and ($\widehat{a}_t{=}a_L$, $\mathbb{E}_t\widehat{a}_{t+1}{=}\rho_a a_L$, and $\mathbb{E}_t\widehat{a}_{t+2}{=}a_H$) drive a supply-driven expansion and recession, respectively, in period t.

The preference shocks govern the demand-driven business cycle, while the productivity shocks drive the supply-driven business cycle, as stated in Assumption 1. A negative preference shock ($\widehat{\beta}_{t+1} = b_L$) generates a demand-driven expansion. When the discount factor is lower, households prefer to increase consumption in the current period, increasing demand for goods. As the demand goes up, that leads to an increase in labor demand in a monopolistic competition model, with a rise in real wages, so does marginal costs, which lead to higher inflation. A positive preference shock ($\widehat{\beta}_{t+1} = b_H$), in contrast, leads consumers to postpone their consumption, resulting in a demand-driven recession. On the other hand, a positive productivity shock ($\widehat{a}_t = a_H$) raises marginal product of labor, leading to an increase in supply of goods, which generates a supply-driven expansion in output. A negative productivity shock ($\widehat{a}_t = a_L$) causes a supply-driven recession. Unlike the preference shock, we assume a persistent productivity shock to ensure a positive response of output to a positive productivity shock, which we will discuss in the proof of Proposition 1 in Appendix A.1.2 in detail. There is also empirical evidence to support the fact that a productivity shock is more persistent than a preference shock.[10]

Proposition 1. In response to a preference shock, output ($\widehat{y}_t$) and inflation ($\widehat{\pi}_t$) co-move,

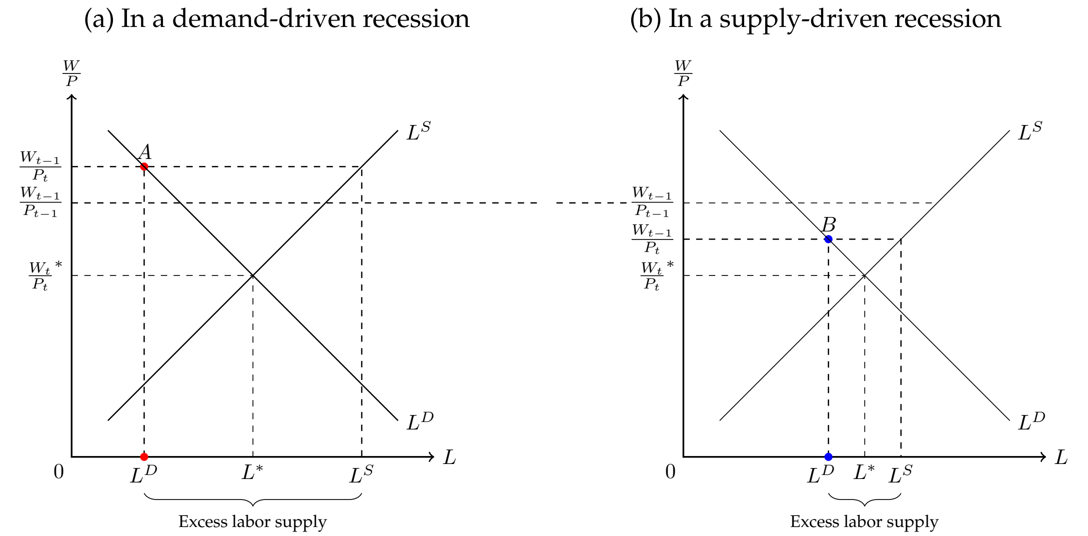
[10]A vast literature uses a unit root process for technology shocks and others estimate the autoregressive parameter to be large, as discussed in more detail when we calibrate the quantitative model.

and in response to a technology shock, output and inflation move in the opposite direction. That is,

$$\frac{\partial \widehat{y}_t}{\partial \widehat{\beta}_{t+1}} < 0; \frac{\partial \widehat{\pi}_t}{\partial \widehat{\beta}_{t+1}} < 0, \text{ and } \frac{\partial \widehat{y}_t}{\partial \widehat{a}_t} > 0; \frac{\partial \widehat{\pi}_t}{\partial \widehat{a}_t} < 0.$$

Proof. The proof is available in Appendix A.1.2. [11] □

Figure 1: Labor market equilibrium in a demand-driven vs. supply-driven recession



Notes: The figure illustrates labor market outcomes in a demand-driven recession (left panel) and a supply-driven recession (right panel). Both recessions result in a market clearing real wage that is lower than the previous real wage. The opposite responses of inflation in both recessions lead to different labor market equilibrium. Points A and B represent the labor market equilibrium in a demand-driven and supply-driven recession, respectively.

The inflation response to a recessionary preference shock and productivity shock are the opposite sign. This difference in the inflation response plays a crucial role in determining labor market outcomes in the presence of DNWR. For example, Figure 1 describes the labor market equilibrium in a demand-driven and a supply-driven recession across the two panels. In a recession, assume that the real wage $(\frac{W_{t-1}}{P_{t-1}})$ from the previous period is higher than the current market-clearing real wage $(\frac{W_t}{P_t}^*)$ due to either a positive discount

[11] This is under the assumption that the elasticity of substitution parameter θ is greater than 1, the discount factor β is less than 1 and greater than zero. The government spending share in output, s_g is less than one. The intertemporal elasticity of substitution σ is assumed to be greater than one, while the frequency of price adjustment is ω is less than one. The Taylor coefficient on inflation is assumed to be higher than one. The persistence of productivity shock ρ_a lies between zero and one, but needs to be high enough to ensure that output rises in response to a positive technology shock. When ρ_a is low, an increase in productivity lowers employment and output.

factor shock (shown in Figure 1a) or a negative productivity shock (shown in Figure 1b) in period t.[12] In any recession, nominal wage is not allowed to adjust downwardly (since the DNWR constraint imposes $W_t \geq \gamma W_{t-1}$, where $\gamma = 1$). In contrast, price inflation responds immediately but in the opposite direction. Proposition 1 states that inflation goes down in response to contractionary discount factor shock. The lack of demand lowers the price level. This further raises the real wage and reduces the labor demanded. Point A in Figure 1a represents the combination of real wage and labor used in production in a demand-driven recession. On the other hand, Proposition 1 asserts that the price level goes up in response to contractionary productivity shock. When there is a negative productivity shock, the marginal product of labor goes down, and marginal cost goes up, henceforth, resulting in inflation. This increase in price level lowers real wages, and point B in Figure 1b becomes a labor market outcome in a supply-driven recession. For both cases, the quantity of labor demand (L^D) is less than the quantity of labor supply (L^S), leading to an excess labor supply. The equilibrium level of labor is demand-determined in the recession, or $L = L^D = \min\{L^D, L^S\}$ as $L^D \leq L^S$ when DNWR binds. From this example, we can clearly see that inflationary pressure in a supply-driven recession helps adjust real wages downwardly when DNWR constraint binds. As a result, the equilibrium quantity of labor used in production is higher in a supply-driven recession than in a demand-driven recession, and there is excess labor supply or larger involuntary unemployment in a demand-driven recession.

Proposition 2. In a model without DNWR, the government spending multiplier takes the same value M_y in expansion and recession states, i.e. is acyclical.

Proof. The government spending multiplier is

$$M_y \equiv \frac{\partial \widehat{y}_t}{\partial \widehat{g}_t} \frac{1}{s_g} = \frac{\omega\theta}{\omega + \Psi\alpha_\pi(1-\omega)(1-\omega\beta)(\varphi-1)} > 0,$$

regardless of the shock processes and the state of the economy. Under the typical calibrated parameter values, M_y>0. The detailed proof is available from Appendix A.1.2. □

In the absence of DNWR constraint, the model is fully symmetric and government spending multiplier is acyclical, as stated in Proposition 2. This is the case in a standard New Keynesian model, and for typically calibrated values $M_y > 0$. An increase in government spending increases aggregate demand, which leads to a rise in labor demand, given the nominal price rigidities. This leads to a higher wage rate and labor, leading to

[12]Note that the previous real wage ($\frac{W_{t-1}}{P_{t-1}}$) and the current market clearing wage ($\frac{W_t}{P_t}^*$) in both figures are assumed to be the same.

an overall rise in output. Under our assumption of GHH preferences, we eliminate any movement in the labor supply curve due to negative wealth effects. The importance of these preferences are apparent if we consider a flexible price case, where $\omega = 0$, and that results in a multiplier of zero, since both labor supply and labor demand do not respond to an increase in government spending.

Next we consider the case where a contractionary preference or technology shock hits the economy such that it leads to DNWR constraint binding.

Proposition 3. When DNWR binds in period t under the expectation of achieving full employment in period $(t+1)$, the spending multiplier is M_{DNWR} , which is bigger than M_y – the multiplier when DNWR does not bind.

Proof. When DNWR constraint binds, we show that the government spending multiplier for output is

$$M_{DNWR} = \theta > M_y = \frac{\omega\theta}{\omega + \Psi\alpha_\pi(1-\omega)(1-\omega\beta)(\varphi - 1)}$$

Detailed proof is available in Appendix A.1.2. □

Proposition 3 shows that government spending multiplier is more effective when DNWR is a binding constraint. As long as DNWR constraint binds, an increase in government spending raises equilibrium labor used in production without raising nominal wage. The increase in labor is higher with a binding DNWR constraint than the case without binding DNWR constraint. When DNWR constraint does not bind, an increase in labor demand raises wage, diluting the effect of an increase in labor demand on equilibrium labor. On the other hand, there is no inflationary pressure on price with a binding DNWR constraint since real wages, henceforth, marginal cost do not change.[13] The real interest rate thus stays the same, ruling out crowding out effects on private consumption.[14] Overall, we document that government spending is more effective as long as DNWR constraint binds because 1) it increases labor without raising nominal wages and 2) it does not raise real interest rate. Thus, the government spending multiplier is state-dependent in the presence of DNWR. In an expansion, nominal wages go up and DNWR does not bind, whereas DNWR constraint binds in a recession. Thus, based on Proposition 3, a spending multiplier can be higher in a recession than in an expansion.

[13]Note that $\frac{\partial\widehat{\pi_t}}{\partial\widehat{g_t}} = H_\pi = 0$ from the proof of Proposition 3, where DNWR binds.

[14]This statement is true under absolute DNWR. Once we allow $\gamma < 1$ in the quantitative analysis, the real interest rate rises in response to an increase in government spending.

Lemma 1. Assume the economy is at the steady-state in period $t-1$, $\widehat{w}_{t-1} = 0$. In the presence of DNWR constraint ($\gamma = 1$), a positive discount factor shock or a negative productivity shock triggers DNWR constraint to bind and induces unemployment in period t.

Proof. The proof is available in Appendix A.1.2. □

To understand the role of the source of the business cycle in determining the government spending multipliers, the key is to consider whether and to what extent DNWR becomes a binding constraint. From Lemma 1, we know that both a positive discount factor shock and a negative productivity shock can lead to the DNWR constraint to bind. Given the size of the contractionary shock in each recession, Lemma 2 documents the size of the lowest government spending that can restore the full employment equilibrium in a demand-driven and supply-driven recession, $c_d(\beta_H)$ and $c_s(a_L)$, respectively. As long as government spending is less than the thresholds, DNWR still binds and government spending has an effectively larger multiplier effect on output. Given the same size of productivity shock and discount factor shock, Lemma 3 shows that a government spending shock required to achieve zero unemployment is larger in a demand-driven recession than in a supply-driven recession.

Lemma 2. Assume the economy is at steady-state in period $t-1$, $\widehat{w}_{t-1} = 0$. In a demand-driven recession, if government spending is less than $\frac{\Psi}{\theta s_g}\beta_H \equiv c_d(\beta_H)$, DNWR constraint binds, and unemployment is greater than zero. Otherwise, DNWR is no longer a binding constraint, and unemployment is zero. In a supply-driven recession, if government spending is less than $c_s(a_L)$, DNWR constraint binds, and unemployment is greater than zero. Otherwise, DNWR is no longer a binding constraint, and unemployment is zero.

Proof. The proof is available in Appendix A.1.2. □

Lemma 3. Under the assumption that $|\beta_H| = |a_L|$, it can be shown that $0 < c_s(a_L) < c_d(\beta_H)$. In other words, the government spending required to ensure DNWR is no longer binding is smaller in a supply driven recession than a demand driven recession.

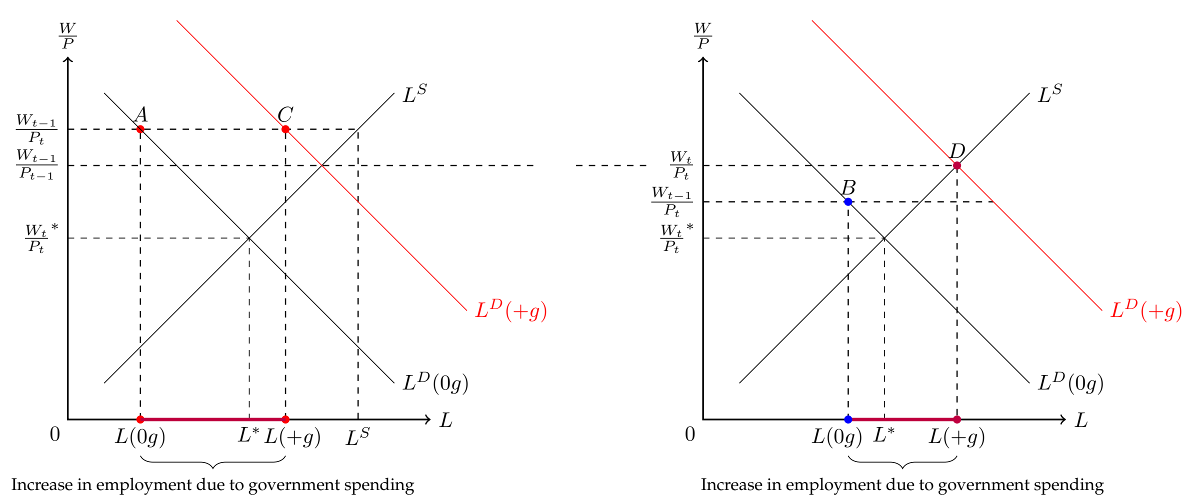
Proof. The proof is available in Appendix A.1.2. □

Based on Lemma 2 and Lemma 3, if government spending is higher than $c_s(a_L)$ but lower than $c_d(\beta_H)$, where $|\beta_H| = |a_L|$, DNWR binds in a demand-driven recession but not in a supply-driven recession. Figure 2 illustrates an increase in labor demand due to an increase in government spending in both recessions described in Figure 1. Note that the increase in labor demand is the same for both cases. In a demand-driven recession, this increase in government spending is not enough to achieve full employment. The new equilibrium is point C in Figure 2a, which shows that the increase in government spending can effectively raise labor without raising real wage. In contrast, this increase in labor demand due to expansionary government spending raises equilibrium real wage in a supply-driven recession, moving to equilibrium point D in Figure 2b. The increase in labor in a demand-driven recession ($L(+g)-L(0g)$ in Figure 2a) is higher than the increase in labor in a supply-driven recession ($L(+g) - L(0g)$ in Figure 2b). Therefore, an increase in output caused by an increase in government spending is larger in a demand-driven recession than in a supply-driven recession.

It is also possible to see in Figure 2 that the size and sign of government spending might also matter for the size of the multiplier. If government spending is less than $c_s(a_L)$ ($c_s(a_L)$ >0), the spending multiplier in recessions would be the same in a demand-driven and supply-driven recession. Negative spending further lowers labor demand, causing DNWR to continue binding. As a result, the spending multiplier would be M_{DNWR} in a recession with contractionary government spending. The spending multipliers in an expansion can also potentially be M_{DNWR} if negative government spending is large enough to offset an increase in aggregate demand in an expansion.

Figure 2: An increase in government spending in a demand-driven vs. supply-driven recession, where $c_s(a_L) < g < c_d(\beta_H)$

(a) In a demand-driven recession (b) In a supply-driven recession



Notes: The figure illustrates the effect of an increase in government spending on labor in a demand-driven recession (left panel) and a supply-driven recession (right panel). Points A and B represent the labor market equilibrium in a demand-driven and supply-driven recession, respectively, without government spending. An increase in government spending shifts labor demand curve to right, resulting an equilibrium point C (left panel) and D (right panel).

Proposition 4. Under the assumption that $|\beta_H| = |a_L|$, i.e. equal sized business cycle fluctuations,

the spending multiplier in a demand-driven recession $\geq$
the spending multiplier in a supply-driven recession $\geq$
the spending multiplier in an expansion,

for a given size of government spending shock.

Proof. In the absence of DNWR, the multipliers are the same regardless of the state of the economy or the source of fluctuation. In the presence of DNWR ($\gamma = 1$), if government spending (g) satisfies $g < c_s(a_L)$, DNWR constraint still binds for both recessions (Lemma 2), thus, the spending multiplier in a demand-driven recession (M^D_{DNWR}) is the same as the spending multiplier in a supply-driven recession (M^s_{DNWR}), which is greater than the spending multiplier in an expansion (M_y). If $c_s(a_L) < g < c_d(\beta_H)$, DNWR condition binds in a demand-driven recession but not in a supply-driven recession. In this case, the spending multiplier in a demand driven recession is M^D_{DNWR} , which is higher than the spending multiplier in a supply driven recession when DNWR is not a binding constraint, equal to the spending multiplier in an expansion, M_y. If $c_s(a_L) < c_d(\beta_H) < g$, government spending is large enough to raises nominal wages and achieve full employment, the spending multiplier would be M_y regardless of the source of fluctuation and the state of business cycle. □

The analytical results show that government spending is more effective when DNWR constraint binds, highlighting the main mechanisms in place. Notably, the opposing response of inflation to a preference shock versus a technology shock suggests that the degree to which the DNWR constraint binds differs across recessions led by these two different shocks. Thus, Proposition 4 states that government spending multiplier is likely to be to larger in a demand-driven recession than a supply driven recession. From the analytics, it is also clear that the relative size of the shocks and government spending determine when DNWR becomes a binding constraint and how different the multipliers are across states of the economy.

4 Quantitative measures of state-dependent government spending multipliers

In this section we simulate a calibrated quantitative model to generate government spending multipliers under various scenarios, distinguishing between expansions and recessions and considering alternative sources of business cycles. Note, in order to impose an occasionally binding DNWR constraint in the model, we use the occbin toolkit of Guerrieri and Iacoviello (2015). We relax some of the strong assumptions underlying the derivation of our analytical results including doing away with absolute downward rigidity, i..e. $\gamma = 1$.

We generalize the monetary policy rule, so that the nominal interest rate (R_t) responds to the deviations of the inflation rate and output from their own steady state, which is summarized as

$$\frac{R_t}{R} = (\frac{\pi_t}{\pi})^{\alpha_\pi}(\frac{y_t}{y})^{\alpha_y},$$

where π and y stand for the steady-state level of inflation and output, respectively.

We also assume that the discount factor, aggregate productivity, and government spending shocks follow AR(1) processes:

$$\ln\frac{\beta_t}{\beta} = \rho^\beta \ln\frac{\beta_{t-1}}{\beta} + \epsilon_t^\beta, \tag{7}$$

$$\ln\frac{A_t}{A} = \rho^A \ln\frac{A_{t-1}}{A} + \epsilon_t^A, \text{ and} \tag{8}$$

$$\ln\frac{g_t}{g} = \rho^g \ln\frac{g_{t-1}}{g} + \epsilon_t^g,$$

where $\epsilon_t^\beta \sim iidN(0,\sigma_\beta^2)$, $\epsilon_t^A \sim iidN(0,\sigma_A^2)$, and $\epsilon_t^g \sim iidN(0,\sigma_g^2)$.

4.1 Parameter calibration

Table 1 shows the calibration of the parameters in the model. The steady-state discount factor (β) is set to be 0.99, implying that the steady-state quarterly real interest rate is 1%. Intertemporal elasticity of substitution, σ, is 1, assuming a log utility function. We set the Frisch elasticity of labor supply $(\frac{1}{\varphi-1})$ to be 0.5, implying φ equals to 3, which is in line with the macro estimate of Frisch elasticity from Chetty, Guren, Manoli, and Weber (2011). χ is set to ensure the steady-state level of labor to be 1. The elasticity of substitution across intermediate goods (θ) is set to be 7.67, implying the steady-state price mark-up is 15%. We set $\omega = 0.75$, implying that the firms have on average one chance to reset their price in a year. The coefficients on inflation and output of monetary policy are set $\alpha_\pi = 1.5$ and $\alpha_y = 0.05$. We set γ, governing the degree of DNWR, as 0.98, which is the lower bound of γ from Schmitt-Grohé and Uribe (2017). This allows at most 8% decline in nominal wages annually, which is a conservative assumption on downward nominal wage rigidity.[15]

The bottom panel of Table 1 presents parameters governing shock processes. Following Fernández-Villaverde et al. (2015), we set the persistence of the discount factor shock (ρ_β) as 0.8 and the standard deviation of the preference shock (σ_β) as 0.0025, implying the half-life of the discount factor is about 3 quarters. The persistence of the productivity shock (ρ_a) is set to be 0.96 and the standard deviation of the productivity shock (σ_a) is 0.45, following Smets and Wouters (2007). We estimate the AR(1) process using detrended real government spending data from 1960 to 2019 and set $\rho_g = 0.81$ and $\sigma_g = 0.009$.[16]

Table 1: Calibrated parameters

Parameters	Value	Description
β	0.99	Discount factor
σ	1	Intertemporal elasticity of substitution
φ	3	Frisch elasticity
θ	7.67	Elasticity of subtitution across goods
ω	0.75	Degree of price stickiness
α_π	1.5	Taylor coefficient
α_y	0.05	Taylor coefficient
γ	0.98	DNWR
		Shock processes
ρ_β	0.8	Persistence of preference shock
σ_β	0.0025	Standard deviation of preference shock
ρ_a	0.95	Persistence of productivity shock
σ_a	0.45	Standard deviation of productivity shock
ρ_g	0.81	Persistence of government spending shock
σ_g	0.017	Standard deviation of government spending shock

Note: Time unit is a quarter.

[15]Equation (2) implies that when there is an excess labor supply, $n_t^s > n_t$, DNWR constraint binds, $W_t = \gamma W_{t-1}$. Based on the previous equation, we can calibrate using the hourly wage growth rates when we had a huge increase in unemployment during the Great Recession. Schmitt-Grohé and Uribe (2016) point out that nominal hourly wage growth rates reflect the long-run growth, while the model is abstract from it. Thus, we have to deflate the hourly wage growth rate by the long-run growth rate of the United states. The average hourly earnings quarterly growth rate (BLS series ID: CES0500000003) from 2008 to 2010 is 0.6% and the long-run average quarterly growth rate in real GDP from 1947 to 2019 is 0.8%. This implies γ equals 0.998. The recent literature sets γ higher than 0.98. For example, Rognlie and Auclert (2020) and Dupraz, Nakamura, and Steinsson (2019) use $\gamma = 1$. Barnichon, Debortoli, and Matthes (2020) allow annualized wage deflation up to 4%, implying $\gamma = 0.99$.

[16]We applied the HP filter to real government spending data - the sum of government consumption expenditure and gross government investment minus consumption of fixed capital, deflated by the GDP deflator, following by Shen and Yang (2018).

4.2 Quantitative results

4.2.1 Business Cycle fluctuations under supply and demand shocks

We begin by considering the impulse responses to both contractionary and expansionary supply and demand shocks. The size of the shock is normalized to match the average output gap during the Great Recession. According to the Congressional Budget Office estimates,[17] the average output gap from 2008 to 2010 was 4%. We consider productivity and discount factor shocks to match this impact on output in a recession. This results in considering a 1.7% deviation from the steady-state value of the discount factor and 2.9% deviation from the steady-state value of productivity. Both shock processes follow AR(1) process, following Equation (7) and Equation (8).[18]

Figure 3 displays impulse response in a demand-driven expansion and recession, without government spending. In response to a negative discount factor shock (shown with solid blue lines), consumers spend more in the current period leading to a demand-driven expansion. An increase in demand raises inflation and equilibrium labor. As there are no frictions in adjusting nominal wages upward, the labor market always clear, and the unemployment rate is zero.

When it comes to a positive discount factor shock (shown with dashed red lines in Figure 3), consumers postpone current consumption, which causes a recession. As labor demand decreases, there is downward pressure on wage. Although real wage goes up more than 4% in an expansion, downward adjustment of real wage is about 1% at the beginning of the recession due to DNWR constraint and deflation. The DNWR constraint allows at most 2% downward adjustment of real wage. At the same time, there is deflation that drives the real wages upward. The comovement of inflation and output, shown in Proposition 1, exacerbates the labor market outcome and raises unemployment.

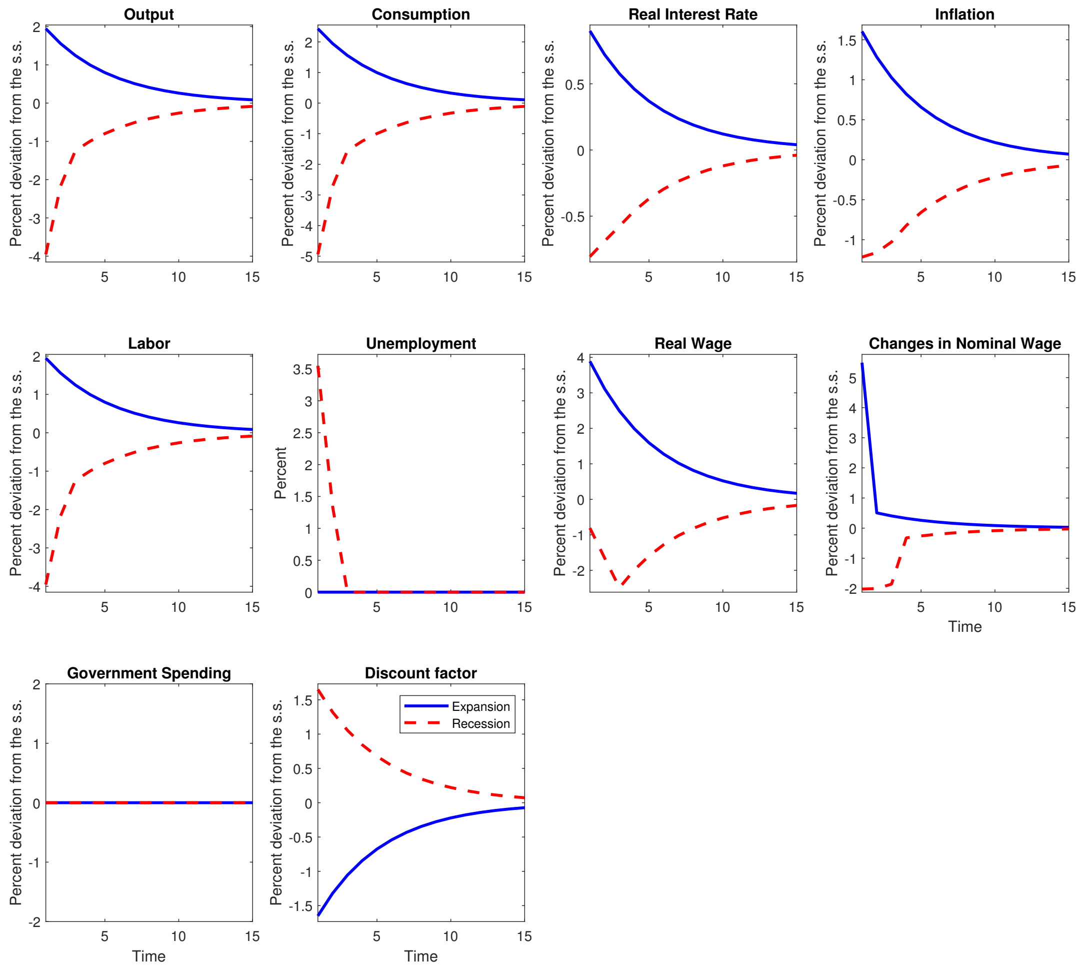
Binding DNWR constraint generates an asymmetric business cycle. Given the same size of the discount factor shock, we find that the drop in output in a recession is greater than the increase in output in an expansion in absolute values. DNWR is the binding constraint in a recession – rationing the labor market, while there is no restriction in raising wages in an expansion – clearing the labor market. The asymmetric constraint on nominal wages leads to asymmetric responses of variables.

Figure 4 shows a supply-driven business cycle, without government spending. The solid blue lines display impulse responses in the supply-driven expansion, followed by a positive technology shock. The dashed red lines represent impulse responses in a supply-

[17]Source: https://fred.stlouisfed.org/graph/?g=f1cZ.

[18]We determine the size of the shock based on the average size of the output gap during the Great Recession, however, the slow recovery during the Great Recession was not matched in the following exercises.

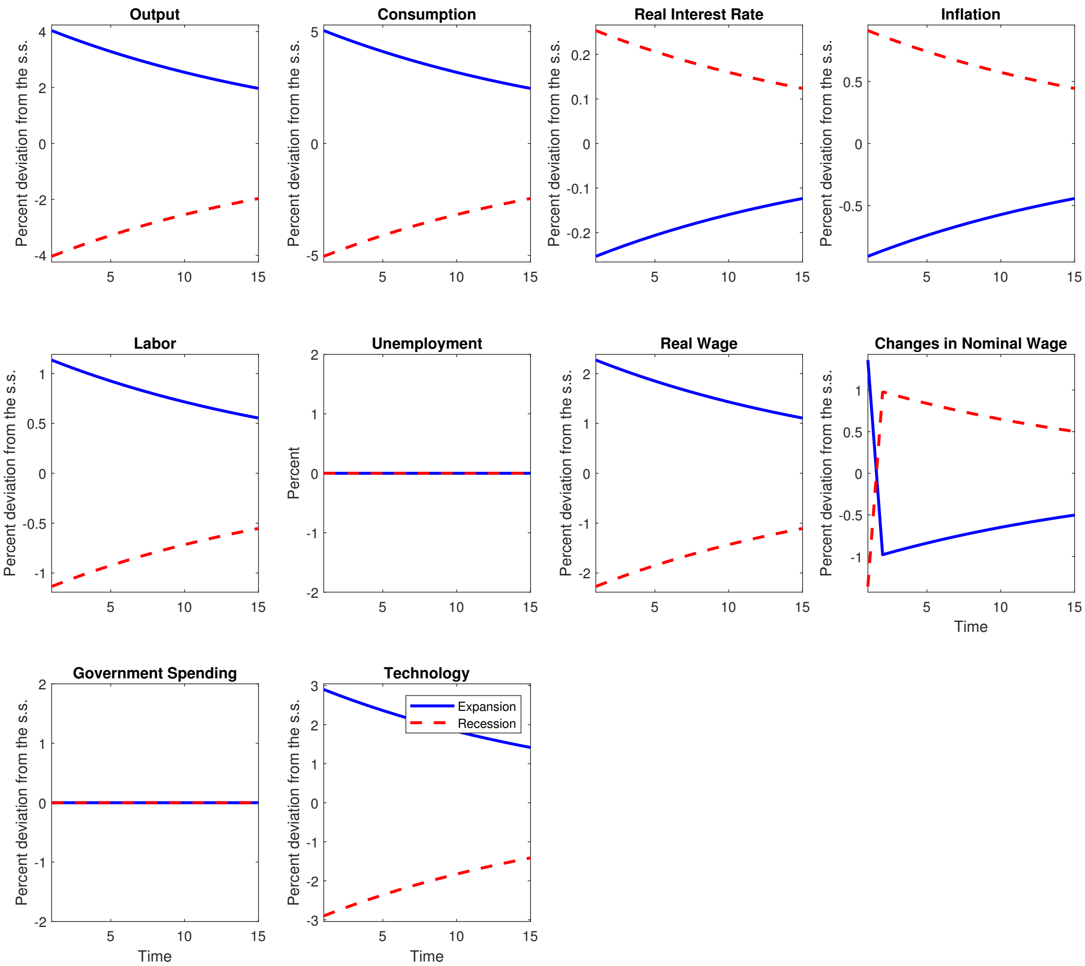
Figure 3: Demand-driven business cycle



Notes: This graph shows impulse responses to a positive and a negative discount factor shock. The solid blue line corresponds to a negative discount factor shock (a demand-driven expansion), and the dashed red line represents impulse responses to a negative discount factor shock (a demand-driven recession). $\pm 1.7\%$ deviation of the discount factor shocks are imposed. All graph is drawn in terms of the percent deviations from its steady-state except the unemployment rate. The y-axis of the unemployment rate is percent.

driven recession in response to a negative technology shock. As shown in Proposition 1, inflation and output move in the opposite directions in the supply-driven recession. In a recession, the marginal product of labor goes down, and firms hire fewer labor. Accordingly, nominal wage goes down about 1.5%. As we allow the downward adjustment of nominal wage up to 2%, the DNWR constraint does not bind. Consequently, the labor market clears, and the unemployment rate is zero. Unlike the demand-driven recession, the downward adjustment of real wage is greater than that of nominal wage in the supply-driven recession due to inflation. This is also highlighted in the analytical section. The supply-driven business cycle is fully symmetric as DNWR does not bind.

Figure 4: Supply-driven business cycle



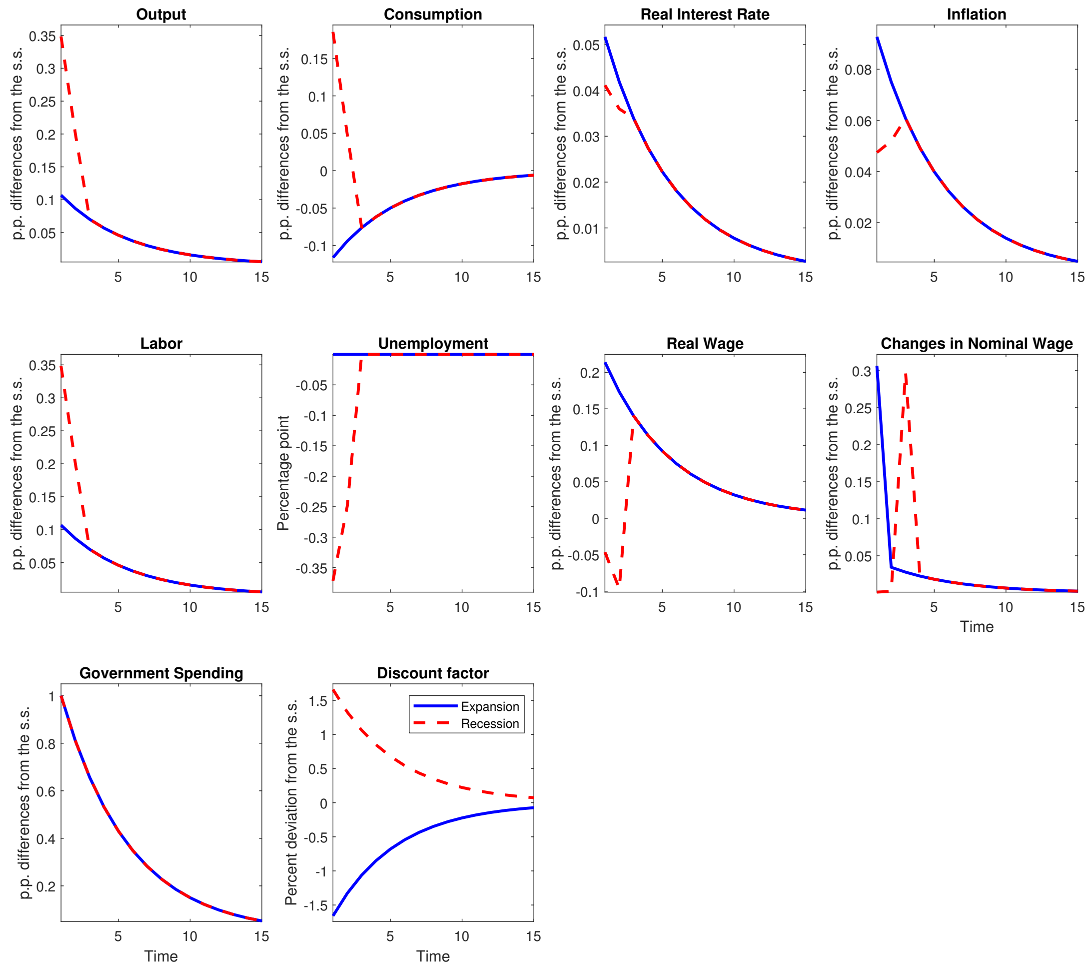
Notes: This graph displays impulse responses to a positive and a negative productivity shock. The solid blue lines correspond to a positive productivity shock (a supply-driven expansion). The dashed red lines represent impulse responses to a negative productivity shock(a supply-driven recession). $\pm 2.9\%$ deviation of the technology shocks are imposed. All graph is drawn in terms of the percent deviations from its steady-state except the unemployment rate. The y-axis of the unemployment rate is percent.

4.2.2 State-dependent effects of government spending

Now let us consider the effect of government spending relying upon the state of the economy and the source of fluctuation. Figure 5 shows the differences of impulse responses with and without government spending in a demand-driven expansion (shown with the solid blue lines) and a demand-driven recession (shown with the dashed red lines). We consider a 1% deviation of government spending from its steady state.

The increase in labor is greater in a demand-driven recession than in a demand-driven expansion. Regardless of the state of the economy, an increase in government spending raises labor and output. In a recession, an increase in government spending does not raise nominal wages immediately since DNWR is a binding constraint. While nominal wage

Figure 5: Effects of government spending shock for demand-driven business cycle

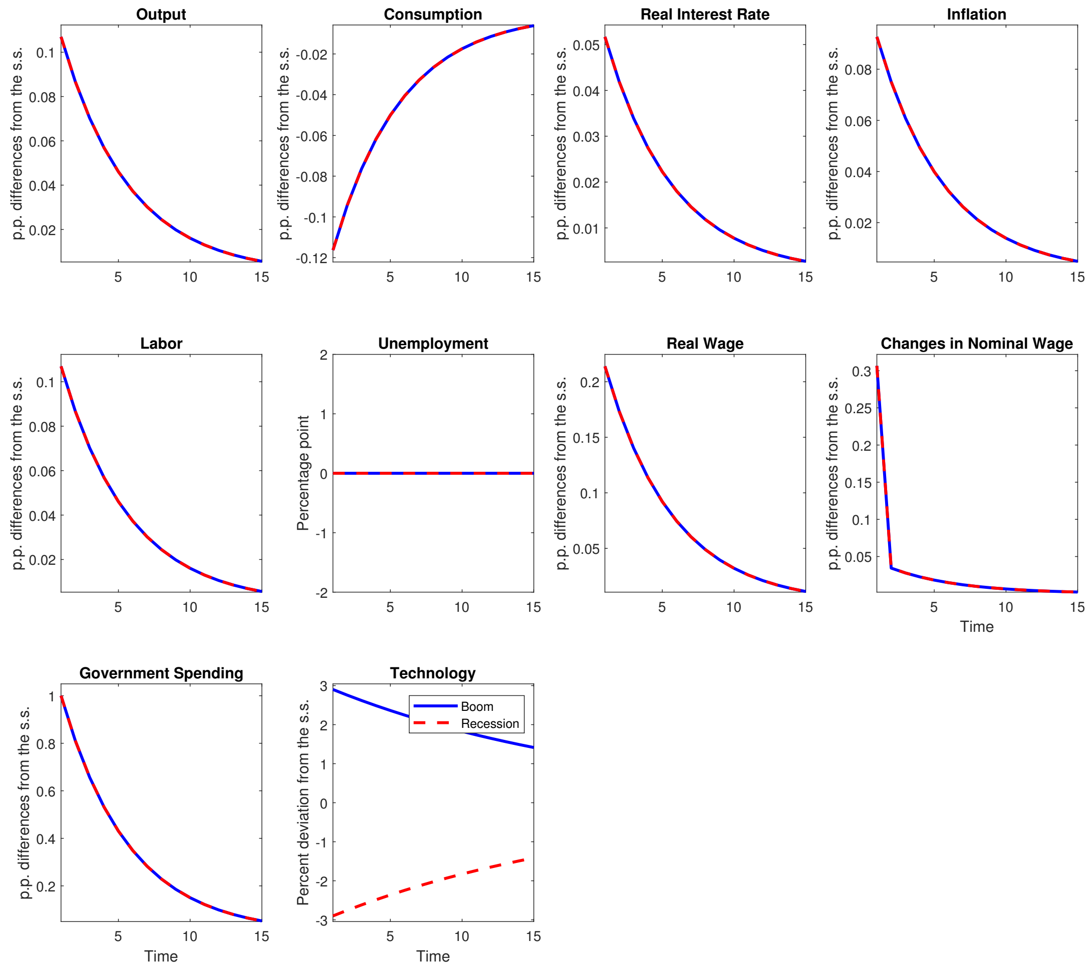


Notes: This graph displays the differences of impulse responses with government spending compared to the one without government spending in a demand-driven expansion (solid blue lines) and a demand-driven recession (dashed red lines). $\pm 1.7\%$ deviation of the discount factor shocks are imposed. All graph is drawn in terms of the percentage points differences from its steady state except the unemployment rate and the discount factor. The y-axis of the unemployment rate is percentage point.

is fixed in a recession, inflation increases due to an increase in demand. As a result, real wage goes down, stimulating the labor market. In contrast, in an expansion, real wage increases in response to an increase in demand. This increase in real wage dilutes the effect of the increase in government spending. Therefore, an increase in labor due to expansionary government spending is smaller in a boom compared to bust. Similarly, the increase in government spending lowers the unemployment rate in a recession when DNWR is a binding constraint, while it does not affect unemployment in an expansion. These results in a demand-driven business-cycle are consistent with Shen and Yang (2018).

Furthermore, the increase in inflation is weaker in a demand-recession than in an demand-driven expansion. An increase in government spending in a recession lowers

Figure 6: Effects of government spending shock for supply-driven business cycle



Notes: This graph displays the differences of impulse responses with government spending compared to the one without government spending in a supply-driven expansion (solid blue line) and a supply-driven recession (dashed red line). $\pm 2.9\%$ deviation of the technology shocks are imposed. All graph is drawn in terms of the percentage points differences from its steady state except the unemployment rate and the discount factor. The y-axis of the unemployment rate is percentage point.

real wage and thus marginal cost. This weakens the response of inflation caused by an increase in demand. The weaker response of inflation in a recession leads to a smaller response of nominal interest rate according to Taylor rule. Consequently, there is a smaller increase in the real interest rate in a recession, limiting the crowding-out effect on private consumption. To summarize, an increase in government spending is more effective in a demand-driven recession when DNWR constraint binds because 1) it can increase the quantity of labor without raising nominal wage, and 2) it has less inflationary pressure leading to a smaller rise in real interest rates. This result is consistent with Proposition 3 from Section 3 that government spending is more effective when DNWR is a binding constraint. In conclusion, government spending is state-dependent in a demand-driven business cycle and much larger in a recession period than an expansion.

Figure 6 displays the differences in impulse response in a supply-driven business cycle with and without government spending. Since the DNWR constraint does not bind in a supply-driven recession (refer to Figure 4), the responses of the macroeconomic variables are the same regardless of the state of the economy. This result is consistent with Proposition 2 that the government spending multipliers are acyclical in a supply-driven business cycle when DNWR constraint is not a binding constraint.

Table 2: Cumulative output and consumption multipliers by the source of fluctuation

		Demand-driven business cycle				Supply-driven business cycle		
		Impact	4 quarters	20 quarters		Impact	4 quarters	20 quarters
Output Multiplier	Expansion	0.535	0.535	0.535	Expansion	0.535	0.535	0.535
	Recession	1.742	1.129	0.879	Recession	0.535	0.535	0.535
Consumption Multiplier	Expansion	-0.465	-0.465	-0.465	Expansion	-0.465	-0.465	-0.465
	Recession	0.742	0.129	-0.121	Recession	-0.465	-0.465	-0.465

Notes. This table reports the cumulative output and consumption multipliers in an expansion and a recession depending on the source of fluctuation. The cumulative output and consumption multipliers are calculated as $\Sigma_{i=0}^{i=k-1} \frac{\Delta y_{t+i}}{(1+r_{t+i})} \big/ \Sigma_{i=0}^{i=k-1} \frac{\Delta g_{t+i}}{(1+r_{t+i})}$ and $\Sigma_{i=0}^{i=k-1} \frac{\Delta c_{t+i}}{(1+r_{t+i})} \big/ \Sigma_{i=0}^{i=k-1} \frac{\Delta g_{t+i}}{(1+r_{t+i})}$, respectively, where Δ denotes the level differences of each variable with and without government spending and r_t is the real interest rate.

Table 2 summarizes the cumulative output and consumption multipliers depending on the state of the economy and the source of fluctuation. The multipliers are state-dependent (countercyclical) in the demand-driven business cycle taking a value above 1 (1.7 on impact) in a recession and 0.5 in an expansion. This larger multiplier in the recession is driven by a positive multiplier for consumption, at least in the short-run, while the consumption multiplier is negative during an expansion. On the other hand, multipliers are acylical in the supply-driven business cycle. The multipliers are higher in a demand-driven recession when DNWR constraint binds as shown in Proposition 4. Nominal wage goes up in an expansion, and the drop in nominal wage in a supply-driven recession does not trigger a binding DNWR constraint in the baseline specification, whereas DNWR binds in a demand-driven recession. As nominal wage gradually adjusts in a demand-driven recession, the difference of cumulative multipliers in a demand-driven recession and an expansion dissipates over time. Thus, both the underlying economic states and the source of fluctuations matter in determining the size of spending multipliers.

4.3 Robustness checks and additional explorations

Table 3: Cumulative output and consumption multipliers by the source of fluctuation

		Demand-driven business cycle				Supply-driven business cycle		
		Impact	4 quarters	20 quarters		Impact	4 quarters	20 quarters
		A. Mild business cycle (Half size of the baseline shock)						
Output	Expansion	0.535	0.535	0.535	Expansion	0.535	0.535	0.535
Multiplier	Recession	0.819	0.630	0.590	Recession	0.535	0.535	0.535
Consumption	Expansion	-0.465	-0.465	-0.465	Expansion	-0.465	-0.465	-0.465
Multiplier	Recession	-0.181	-0.370	-0.410	Recession	-0.465	-0.465	-0.465
		B. Severe business cycle (One and a half size of the baseline shock)						
Output	Expansion	0.535	0.535	0.535	Expansion	0.535	0.535	0.535
Multiplier	Recession	2.286	1.654	1.183	Recession	0.535	0.535	0.535
Consumption	Expansion	-0.465	-0.465	-0.465	Expansion	-0.465	-0.465	-0.465
Multiplier	Recession	1.286	0.654	0.183	Recession	-0.465	-0.465	-0.465
		C. Large government spending shock (10% deviation from the steady-state)						
Output	Expansion	0.535	0.535	0.535	Expansion	0.535	0.535	0.535
Multiplier	Recession	1.459	0.948	0.774	Recession	0.535	0.535	0.535
Conumption	Expansion	-0.465	-0.465	-0.465	Expansion	-0.465	-0.465	-0.465
Multiplier	Recession	0.459	-0.052	-0.226	Recession	-0.465	-0.465	-0.465
		D. Negative government spending shock (Negative 1% deviation from the steady-state)						
Output	Expansion	0.535	0.535	0.535	Expansion	0.535	0.535	0.535
Multiplier	Recession	2.051	1.428	1.052	Recession	0.535	0.535	0.535
Conumption	Expansion	-0.465	-0.465	-0.465	Expansion	-0.465	-0.465	-0.465
Multiplier	Recession	1.051	0.428	0.052	Recession	-0.465	-0.465	-0.465
		E. Less rigid DNWR ($\gamma = 0.96$)						
Output	Expansion	0.535	0.535	0.535	Expansion	0.535	0.535	0.535
Multiplier	Recession	1.124	0.733	0.649	Recession	0.535	0.535	0.535
Conumption	Expansion	-0.465	-0.465	-0.465	Expansion	-0.465	-0.465	-0.465
Multiplier	Recession	0.124	-0.267	-0.351	Recession	-0.465	-0.465	-0.465

Notes. This table reports the cumulative output and consumption multipliers in an expansion and a recession depending on the source of fluctuation. The cumulative output and consumption multipliers are calculated as $\Sigma_{i=0}^{i=k-1} \frac{\Delta y_{t+i}}{(1+r_{t+i})} \Big/ \Sigma_{i=0}^{i=k-1} \frac{\Delta g_{t+i}}{(1+r_{t+i})}$ and $\Sigma_{i=0}^{i=k-1} \frac{\Delta c_{t+i}}{(1+r_{t+i})} \Big/ \Sigma_{i=0}^{i=k-1} \frac{\Delta g_{t+i}}{(1+r_{t+i})}$, respectively, where Δ denotes the level differences of each variable with and without government spending and r_t is the real interest rate.

4.3.1 Size of business cycle fluctuations

The magnitude of the spending multipliers also depend on the size of underlying fluctuations. Panel A and B of Table 3 report the cumulative output and consumption multipliers for mild and severe business cycles, respectively. The multipliers in a demand-driven recession rise with the size of the discount factor shock. In our baseline experiment the size of the recession is calibrated to match the depth of the Great Recession. If we consider a milder recession, generated by half the size of the baseline discount factor, then the impact output multiplier is 0.89, i.e. less than one even in a demand-driven recession. In a severe demand-driven recession, the unemployment rate is high. Under these circumstances, an additional increase in demand greatly increases output leading to a significantly larger output and consumption multiplier. In contrast, the spending multipliers are the same in a supply-driven business cycle since DNWR is not a binding constraint.

4.3.2 Size and sign of government spending

The size and the sign of government spending also play a role in determining the magnitude of spending multipliers. A large increase in government spending greatly reduces the labor market distortions. This reduces the overall spending multiplier in a demand-driven recession. (See Panel C of Table 3) The multiplier for a ten times larger shock to government spending yields a multiplier of 1.46 on impact in a demand driven recession, compared to 1.74 for a one percent increase in our baseline case. As marginal increases in government spending reduces the labor market distortion to a smaller extent, it becomes less effective in leading to a sizable increase in output. However, the size of government spending does not affect the spending multiplier in a supply-driven business cycle since DNWR does not bind.

A negative government spending in a demand-driven recession further exacerbates the labor market, raising the spending multiplier to above 2. (See Panel D of Table 3) This result is consistent with empirical findings from Barnichon, Debortoli, and Matthes (2020) that suggest the spending multiplier for negative shock to government spending is higher than the multiplier for a positive shock. This suggests that fiscal austerity is particularly harmful in a demand driven recession. Once again, since the DNWR does not bind in a supply driven recession, the sign of government spending intervention does not affect the size of the multipliers.

4.3.3 Alternative degree of DNWR

We also consider an alternative degree of downward nominal wage rigidity, and relax the degree of downward nominal wage rigidity. Once we assume a more downwardly flexible wage ($\gamma = 0.96$), it results in a lower multiplier in a demand-driven recession, as shown in Panel E of Table 3. This is because the extent of binding DNWR is smaller than the baseline case where we considered $\gamma = 0.98$.

5 Time series empirical evidence

5.1 Econometric Methodology

In order to investigate empirically whether government spending multipliers are state-dependent and if the nature of recession matters, we estimate state dependent local projections a la Jordà (2005). Notably, we exploit the rich long time series data for U.S. where there is large variation in government spending, the unemployment rate and also periods of high and low inflation. We employ the one-step IV estimation procedure for fiscal multipliers as introduced in Ramey and Zubairy (2018). In departure from their analysis, we distinguish not only between low and high unemployment periods, but we also consider high unemployment periods which are characterized by low inflation, which can be thought of as demand-driven recessions, and alternatively periods with high unemployment and high inflation, which correspond to supply-driven recessions.[19] We consider the following state-dependent local projection model,

$$\sum_{j=0}^{h} y_{t+j} = \sum_{d} \mathbb{I}(\text{State } d) \left[\gamma_{d,h} + \phi_{d,h}(L) z_{t-1} + m_{d,h} \sum_{j=0}^{h} g_{t+j} \right] + \omega_{t+h},$$

where y_t is real GDP and g_t is real government spending, both normalized by trend GDP.[20] The normalization and consideration of cumulative GDP and government spending variables ensures that the coefficient m_h can be interpreted as the cumulative government spending multiplier at horizon h in a given state. In our baseline specification we consider an indicator function for three states, which correspond to $\mathbb{I}(L(u_t))$, the state where unemployment is low, $\mathbb{I}(H(u_t)) \times \mathbb{I}(L(\pi_t))$, periods of high unemployment and low inflation and $\mathbb{I}(H(u_t)) \times \mathbb{I}(H(\pi_t))$ which correspond to periods of high unemployment and high inflation. We use $\mathbb{I}_t \times shock_t$ as the instruments for the respective interaction of cumulative government spending with the state indicator, where in our baseline specification

[19] Ghassibe and Zanetti (2020) also distinguish between supply and demand-driven recession similarly, and present similar state-dependent results for effects of military news shocks for a slightly shorter sample. We could consider a four state analysis, where we also consider low unemployment rate with high and low inflation respectively, i.e. demand and supply-driven expansions. However, we run into weak instrument issues when we consider this finer definition of a state, particularly for the low unemployment and low inflation state, which for the full sample with military news shocks has F-stats around 6 and 7 at 2 and 4 year horizon, respectively.

[20] Trend or potential GDP is constructed by using a sixth-order polynomial. This normalization for GDP and government spending ensures we do not have to use the average share of government spending to GDP to convert government spending into GDP units and thus to get the multipliers. Ramey and Zubairy (2018) show that this approach can bias the multipliers, particularly in samples where there is large variation in spending as a share of GDP.

the shock we consider is the military news variable from Ramey and Zubairy (2018). Since this LP-IV approach allows us to consider multiple instruments, we also consider the case with both military news and identification based on Blanchard and Perotti (2002).

Our data set constitutes of quarterly data for the U.S. spanning 1889Q1-2017Q4. We define inflation as year-over-year growth of the GDP deflator, and use data for GDP, unemployment rate, government spending and GDP deflator from Ramey and Zubairy (2018). Our baseline measure of narrative military news variables also comes from Ramey and Zubairy (2018). In order to define states, we consider high or low unemployment periods where the unemployment rate is above or below the threshold of 6.5 %, respectively, as considered by Ramey and Zubairy (2018). We further consider high and low inflation periods, based on quarterly inflation being above or below a threshold of 4%.[21] Using this distinction in the inflation rates to distinguish between the type of recession implies that the Great Depression, for the most part, and the Great Recession were demand-driven recessions, and the recessions in the 1970s and early 1980s are supply-driven recessions.[22]

5.2 Estimation Results

Table 4 shows our baseline results, where we consider military news variable to identify the government spending shocks, for estimated state dependent multipliers. Multipliers are defined as cumulative multipliers, which account for the cumulative dynamics of output and government spending, as advocated for in Mountford and Uhlig (2009). The linear and two state multipliers replicate the findings of Ramey and Zubairy (2018). Notably, if we do not condition on the nature of a recession, the spending multipliers are not estimated to be state dependent and are not statistically different across periods of high and low unemployment. Once we consider three states, we find the 2 year integral multiplier of 0.6 in the low unemployment state, which is close to the linear multiplier. However, at the 2 year horizon, the multiplier in the high unemployment state significantly differs based on inflation; being close to 1 in the low inflation state and close to 0 in the high inflation. The multiplier in the high unemployment/ low inflation state is statistically significantly larger than the multiplier in the low unemployment state. At the 4 year horizon, the low unemployment multiplier is close to the linear multiplier, at close to 0.7. Again, the multipliers are statistically significantly different when the unemploy-

[21]This corresponds to the top 75th percentile of inflation over our entire sample. We conduct additional robustness checks with alternative time-varying threshold for inflation and unemployment in Appendix A.3.

[22]The classification of these different states along with data on military news, unemployment rate and inflation are shown in Figure A.4 in Appendix A.3.

ment rate is high, based on the state of inflation. They are estimated to be about 0.8 and 0.2 across the low and high inflation states, respectively.[23] This provides evidence consistent with our theoretical findings: the government spending multiplier is significantly larger in a demand-driven recession than a supply-driven recession.[24]

Table 4: State-dependent fiscal multipliers for output: military news shocks

	(1)	(2)	(3)	(4)	(5)	(6)
	2-year cumulative multiplier			4-yearcumulative multiplier		
Σg_t	0.6637*** (0.0671)			0.7134*** (0.0436)		
$\Sigma g_t \times \mathbb{I}(L(u_t))$		0.5949*** (0.0905)	0.5949*** (0.0905)		0.6683*** (0.1236)	0.6683*** (0.1240)
$\Sigma g_t \times \mathbb{I}(H(u_t))$		0.6029*** (0.0888)			0.6820*** (0.0536)	
$\Sigma g_t \times \mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))$			0.9886*** (0.1878)			0.7824*** (0.0575)
$\Sigma g_t \times \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))$			-0.1920 (0.1503)			0.2044** (0.0998)
P-value from the test						
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))] = 0$		0.95			0.92	
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))] = 0$			0.09			0.47
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))] = 0$			0.00			0.00
$\Sigma g_t \times [\mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t)) - \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))] = 0$			0.00			0.00
First-stage F statistics						
Linear	19.38			11.22		
$\mathbb{I}(L(u_t))$		8.44	8.07		10.85	10.56
$\mathbb{I}(H(u_t))$					130.20	
$\mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))$			56.37			249.55
$\mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))$			45.89			71.63
Observations	493	493	493	485	485	485

Notes: The top panel panel reports the 2 and 4 year cumulative multiplier along with associated standard errors below. The second panel shows p-values testing whether multipliers are statistically significantly different across states. The last panel shows the first-stage F statistics for military news as an instrument at 2 and 4 year horizons for the given state.

[23]The table reports 2 and 4 year horizons multipliers only, but Figure A.5 in Appendix A.3 shows the multipliers and corresponding standard error bands over the entire 5 year horizon.

[24]The empirical estimates for the average multiplier in a demand-driven recession are close to 1 and smaller than the multipliers from the quantitative model. This is essentially because we simulate a deep recession in a model and as further explorations of the quantitative model reveal, the multiplier in a demand driven recession can even be less than one in a mild recession. Table 4 also reports that the multiplier in a supply-driven recession (periods with high unemployment accompanied with high inflation) is smaller than the multiplier in an expansion. At first glance, it seems contradictory to Proposition 4, but those results are derived under the assumption of the equal sized business cycle for a given size of government spending. However, large government spending in a mild supply-driven recession can generate a relatively smaller multiplier, or a large negative government spending in an expansion can lead to a larger multiplier.

Table 5: State-dependent fiscal multipliers for output: both military news and Blanchard-Perotti (2002) as instruments

	(1)	(2)	(3)	(4)	(5)	(6)
	2-year cumulative multiplier			4-year cumulative multiplier		
Σg_t	0.4175***			0.5639***		
	(0.0979)			(0.0837)		
$\Sigma g_t \times \mathbb{I}(L(u_t))$		0.3343***	0.3343***		0.3873***	0.3873***
		(0.1095)	(0.1081)		(0.1080)	(0.1076)
$\Sigma g_t \times \mathbb{I}(H(u_t))$		0.6185***			0.6809***	
		(0.0921)			(0.0536)	
$\Sigma g_t \times \mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))$			0.6805***			0.7900***
			(0.2122)			(0.0618)
$\Sigma g_t \times \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))$			0.2234*			0.4435***
			(0.1330)			(0.0893)
P-value from the test						
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))] = 0$		0.10			0.02	
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))] = 0$			0.14			0.00
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))] = 0$			0.55			0.72
$\Sigma g_t \times [\mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t)) - \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))] = 0$			0.09			0.00
First-stage F statistics						
Linear	64.59			28.40		
$\mathbb{I}(L(u_t))$		79.26	63.27		24.60	23.45
$\mathbb{I}(H(u_t))$		280.33			72.29	
$\mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))$			56.74			175.79
$\mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))$			68.84			65.65
Observations	493	493	493	485	485	485

Notes: The top panel panel reports the 2 and 4 year cumulative multiplier along with associated standard errors below. The second panel shows p-values testing whether multipliers are statistically significantly different across states. The last panel shows the first-stage F statistics for military news and Blanchard and Perotti (2002) shocks jointly as instruments at 2 and 4 year horizons for the given state.

The primary reason behind conducting a three state analysis and not distinguishing between the inflation rate across the slack states is the extremely low instrumental relevance of military news for the low unemployment and low inflation state. As shown in the bottom panel of Table 4, the instrumental relevance of military news is still rather small in the low unemployment state overall. On the other hand, the alternative leading identification scheme of Blanchard and Perotti (2002), based on assuming that government spending does not respond to contemporaneous output and macroeconomic variables in the same quarter, has very low instrumental relevance in the high unemployment state.[25] In order to deal with these issues, we also conduct the same analysis using both

[25] Ramey and Zubairy (2018) have already shown that beyond the impact, the instrumental relevance

military news and Blanchard and Perotti (2002) shocks as instruments, shown in Table 5. In this case, the multipliers are overall estimated to be smaller, but we do not run into any instrumental relevance issues across the various states and horizons. These results also reveal multipliers that are statistically significantly higher in during periods of slack accompanied by low inflation relative to high inflation. Notably, the 2 year multiplier is close to 0.7 in the high unemployment/ low inflation state and close to 0.2 in the high unemployment/high inflation state. The gap between the two closes at the 4 year horizon where they are 0.8 and 0.4 across low and high inflation states, respectively. The multipliers in the low unemployment states are between 0.3 and 0.4, and statistically significantly smaller than the high unemployment/ low inflation state at the 4 year horizon. Overall, these results also suggest larger spending multipliers in a demand-driven recession than a supply-driven recession.

6 US state-level empirical evidence

6.1 US state-level data

In order to directly explore how DNWR plays a role in determining state-dependent fiscal spending multipliers, we exploit U.S. state-level variations of output, inflation and military spending. This approach also allows us to directly use data on the degree of binding DNWR, which is possible due to recent advances using individual-level panel data on wages. The state-level military spending data also has an advantage over national-level data. While national-level military spending does not exhibit large variations except wartimes, state-level military spending data shows a high variation across the time and cross-sectional dimension.

The state-level annual data sample starts in 1969 and ends in 2018. State-level nominal GDP is from the US Bureau of Economic Analysis (BEA).[26] In calculating real GDP, we use the US aggregate Consumer Price Index (CPI) to deflate nominal GDP followed by BEA - calculating state-level GDP by applying national price deflator to state-level nominal GDP. State-level employment is from Current Employment Statistics (CES) by the Bureau of Labor Statistics (BLS) and the state-level population is available from the US Census Bureau. We use state-level inflation data constructed by Nakamura and Steinsson (2014)

of Blanchard and Perotti shocks become smaller at longer horizons of 2 and 4 years out, based on the underlying identification assumption.

[26]The state-level GDP data is published based on SIC (Standard Industrial Classification) code before 1997 and NAICS (The North American Industry Classification System) code after 1997. We concatenated two data series following Nakamura and Steinsson (2014).

from 1969 to 2008 and later by Zidar (2019) up to 2014. We further extend the state-level inflation from Regional Price Parity (RPP) from Census until 2018.[27]

For state-level military spending, we use data from prime military contracts awarded by the Department of Defense (DOD). Each individual contractor of DOD reports their contract details using DD Form 350, including the service or product supplies, date awarded, principal place of performance, and information about the DOD agency. For each fiscal year[28] between 1966 and 2000, we rely on state-level military prime contract data constructed by Nakamura and Steinsson (2014).[29] For the remaining sample period from 2001 until 2018, we use electronic DD Form 350 data available from www.USAspending.gov.[30]

We measure the extent of binding DNWR as the difference between the share of workers whose year-over-year hourly wage growth rates are (i) zero and (ii) negative for each state and year from 1980 to 2018, constructed by Jo (2020) using Current Population Survey.[31] Jo (2020) shows that in a recession when employment declines, the share of workers with zero wage changes increases disproportionately more than the share of workers with wage cut, which is consistent with models with DNWR among alternative wage setting schemes. Therefore, in this study, we use the state-level differences between the share of workers with zero wage changes and wage cuts as our measure of the degree of binding DNWR for each state and year.

6.2 Econometric approach

The baseline regression equation for state-level analysis is as follows.

[27]Before 1995, Nakamura and Steinsson (2014) use state-level price indices constructed by Del Negro (1998) from 1969. After 1995, both papers by Nakamura and Steinsson (2014) and Zidar (2019) use county and metro level Cost of Living Index (COLI) published by the American Chamber of Commerce Researchers Association (ACCRA), later renamed as Council for Community and Economic Research (C2ER). As regional level COLI is designed to capture differences in price levels across regions within a year, Nakamura and Steinsson (2014) computed the state-level price indices by multiplying population-weighted COLI from the ACCRA for each sate with the US aggregate CPI. We applied for the same procedure to calculate the state-level price indices using the state-level COLI provided by Zidar (2019) and RPP from Census.

[28]Since 1976, the fiscal year has been from October 1 of the previous calendar year to September 30. Before 1976, it was from July 1 of the previous calendar year to June 30.

[29]Nakamura and Steinsson (2014) note that the original data now can be obtained from the US National Archives.

[30]Similar to the data set from Nakamura and Steinsson (2014), we compute the state-level total military spending by adding prime awards amounts to Navy, Army, Air force, and Defense logistics agency for each fiscal year.

[31]Grigsby, Hurst, and Yildirmaz (2019) also explore US-state-level differential wage rigidity, but their sample starts from 2008.

$$\frac{Y_{it} - Y_{it-s}}{Y_{it-s}} = \alpha_i + \gamma_t + \beta \frac{G_{it} - G_{it-s}}{Y_{it-s}} + \text{Controls} + \epsilon_{it}, \tag{9}$$

where Y_{it} denotes per capita real output in state i and G_{it} denotes per capita real military procurement spending in state i in year t, state-fixed effect, α_i, controls for state-specific trends and time-fixed effect, γ_t, controls for aggregate conditions that are common across states such as aggregate monetary policy in each year.

We regress two-year differences in per capita output on the two-year differences in per capita military procurement spending. Both variables are normalized by the two-year lagged per capita output . This normalization helps us control for heteroskedasticity across states, following previous research. We interpret the parameter β of interest as a two-year cumulative spending multiplier. Our military spending data is recorded in the fiscal year, whereas all other data is reported in the calendar year. We expect the biannual regression would resolve these time differences as they overlap for most of the time period, following Nakamura and Steinsson (2014) and Dupor and Guerrero (2017).

In order to address endogeneity concerns, namely that the state-level military spending possibly respond to the current macroeconomic status of each state, we instrument our dependent variables with two variables. The first instrumental variable is the sensitivity of each state's changes in military spending with respect to changes in national military spending, which is introduced by Nakamura and Steinsson (2014). The identifying assumption is that the sensitivity is time-invariant and national military spending is exogenous to relative business cycle conditions of each specific state. We use each state's predicted value of military spending, computed as the estimated elasticity $(\widehat{\psi_i})$ times national military spending growth $\left(\frac{G_t - G_{t-s}}{Y_{t-s}}\right)$, as our instrumental variable. The state-specific sensitivity ψ_i is estimated from the regression equation: $\frac{G_{it} - G_{it-s}}{Y_{it-s}} = \phi_t + \psi_i \frac{G_t - G_{t-s}}{Y_{t-s}} + \epsilon_{it}$.

We also use Bartik type state-specific time-varying instrument variable widely used in the previous literature.[32] We construct the Bartik instrument variable as $B_{it} = s_{it} \frac{G_t - G_{t-2}}{Y_{t-2}}$, where s_{it} is the average level of per capita military procurement spending in that state relative to per capita state output from the previous two years. Using the predetermined share of military spending, we can avoid the reverse causality concern that state differential military spending can be affected by its state-specific current business cycle conditions.

In order to identify state dependent spending multipliers, we add state-level changes

[32] Nakamura and Steinsson (2014), Demyanyk, Loutskina, and Murphy (2019), and Dupor and Guerrero (2017) among others.

in military spending interacted with indicator variables ($\mathbb{I}(\cdot)$), which provide information on US-states-years corresponding to the state of the economy as shown below:

$$\frac{Y_{it} - Y_{it-s}}{Y_{it-s}} = \alpha_i + \gamma_t + \sum_d \beta_d \frac{G_{it} - G_{it-s}}{Y_{it-s}} \mathbb{I}(\text{State } d) + \text{Controls} + \epsilon_{it}. \tag{10}$$

We divide the state of economy based on the level of employment, inflation, and DNWR. The indicator variable for low employment, $\mathbb{I}(\text{L}(e_{it}))$ is one when the HP-filtered cyclical component of state-level employment to population ratio (e_{it}) is lower than 25th percentile of its distribution across US-states-and-years and zero otherwise. In addition, $\mathbb{I}(\text{H}(\pi_{it}))$ indicates high inflation US-states-years, which takes the value of one if biannual state-level inflation (π_{it}) is grater than 75th percentile of its distribution and zero otherwise. Lastly, the dummy variable $\mathbb{I}(\text{H(DNWR)})$ indicates US-states-years when more workers have binding DNWR constraints. $\mathbb{I}(\text{H(DNWR)})$ is one when the biannual changes in the state-level differences between the share of workers with zero wage and the share of workers with wage cut is higher than 75% percentile from its distribution across states and years from 1980 to 2018.[33] We include one biannual lag of the growth rate of output, military spending, and both instrumental variables in order to meet the lead-lag exogeneity condition suggested by Stock and Watson (2018).[34]

6.3 US state level estimation results

Table 6 shows the effect of state-level military procurement spending on output depending upon state-level employment, inflation, and DNWR. To correct for endogeneity bias, we use both instruments - sensitivity and Bartik instruments.[35] The first two columns of Table 6 show baseline spending multipliers for the entire sample periods. The two year cumulative multiplier is 1.7, which lies between the estimates using sensitivity IV and Bartik IV from Nakamura and Steinsson (2014).[36] After controlling for lagged variables shown in column 2, the spending multiplier is higher than the one without lagged con-

[33] $\mathbb{I}(\text{H}(e_{it}))$, indicating high employment US-states-years, $\mathbb{I}(\text{L}(\pi_{it}))$, representing low inflation US-states-years and $\mathbb{I}(L(\text{DNWR}))$ indicating US-states-years with low DNWR are the complement of their relevant respective state defined above.

[34] Chen (2019) and Ramey (2020) point out that instrumental variables can be serially correlated in the US-state-level analysis, not satisfying the lead-lag exogeneity requirement that the external instruments should be uncorrelated with past and future shocks. Thus, adding lagged variables in our regression estimation helps to ensure that our instrumental variables have no serial correlation.

[35] The overidentification test that all instrumental variables are exogenous are not rejected. J statistics from the overidentification test and the corresponding p-values are reported at the bottom of the table.

[36] Note that the sample period of Nakamura and Steinsson (2014) ends in 2008.

Table 6: State-dependent spending multipliers on employment, inflation, and DNWR: Two states

	(1) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(2) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(3) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(4) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(5) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(6) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(7) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(8) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$
$\frac{G_{it}-G_{it-2}}{Y_{it-2}}$	1.6726***	1.9283**						
	(0.4015)	(0.7624)						
$\frac{G_{it}-G_{it-2}}{Y_{it-2}}\mathbb{I}(\mathrm{H}(e_{it}))$			1.3824***	1.5933				
			(0.4773)	(1.0757)				
$\frac{G_{it}-G_{it-2}}{Y_{it-2}}\mathbb{I}(\mathrm{L}(e_{it}))$			2.3310***	2.3947***				
			(0.4890)	(0.7690)				
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\mathrm{H}(\pi_{it}))$					3.0118***	3.6325**		
					(0.9159)	(1.5055)		
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\mathrm{L}(\pi_{it}))$					2.3867***	0.7975		
					(0.8770)	(0.8443)		
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\mathrm{H}(\mathrm{DNWR}))$							4.0763***	2.4331*
							(1.1559)	(1.4094)
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\mathrm{L}(\mathrm{DNWR}))$							3.8122***	1.4727
							(1.0552)	(1.2581)
P-value from the test								
$\frac{G_{it}-G_{it-2}}{Y_{it-2}}[\mathbb{I}(\mathrm{H}(e_{it}))-\mathbb{I}(\mathrm{L}(e_{it}))]=0$			0.11	0.47				
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\mathrm{H}(\pi_{it}))-\mathbb{I}(\mathrm{L}(\pi_{it}))]=0$					0.32	0.04		
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\mathrm{H}(\mathrm{DNWR}))-\mathbb{I}(\mathrm{L}(\mathrm{DNWR}))]=0$							0.74	0.28
Observations	2,450	2,350	2,450	2,350	2,450	2,350	1,450	1,150
Period	1963 - 2018	1963 - 2018	1963 - 2018	1963 - 2018	1963 - 2018	1963 - 2018	1980-2018	1980-2018
Controls		Lagged variables		Lagged variables		Lagged variables		Lagged variables
First-stage F	258.66	11.29	159.00	5.47	19.55	4.51	16.74	30.51
J Statistic	0.17	0.18	4.39	3.41	3.44	4.90	1.29	0.78
Jstat P value	0.68	0.67	0.11	0.18	0.18	0.09	0.52	0.68

Notes: The top panel reports the 2 year cumulative state-level multiplier along with associated standard errors below in parenthesis. The second panel shows p-values testing whether multipliers are statistically significantly different across states. Two instrumental variables are used for the estimation - sensitivity and Bartik instruments. The lagged variables are added as the control variables in Column 2, 4, 6, and 8. The F-statistic corresponds to the Kleibergen-Paap rk Wald statistic. The J-statistics from overidentification tests are reported.

trol variables, while it results in lower first stage F statistics.[37] Column 3 and 4 of Table 6 show state-dependent spending multiplier depending upon the level of the cyclical component of employment. The spending multiplier for slack period is higher than the one for non-slack period, although these two coefficients are not statistically different from each other. Column 5 and 6 of Table 6 show state-dependent spending multipliers depending upon the level of the state-level inflation. Both estimates show higher spending multiplier for the period of high inflation, but the first stage F statistics are rather low in the case where these differences are statistically significant. The spending multiplier is higher when the US-state-year record high DNWR. Controlling for lagged variables, the estimate on the growth of US state-level military spending interacted with high DNWR indicator is statistically significant while the one interacted with low DNWR indicator is

[37]This is because autocorrelation coefficients on the control variables change over time.

not.

Table 7: State dependent spending multipliers on employment, inflation, and DNWR: Three states

	(1) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(2) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(3) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(4) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(5) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$
$\frac{G_{it}-G_{it-2}}{Y_{it-2}}\mathbb{I}(\text{H}(e_{it}))$	1.2028**	1.2679	4.7084***	0.8508	0.6224
	(0.4700)	(1.0371)	(1.6082)	(1.8363)	(1.8048)
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))$	3.8641***	3.8885***			
	(1.0198)	(1.2894)			
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{H}(\pi_{it}))$	0.1548	-1.1779			
	(0.6950)	(1.4811)			
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))$			3.4135***	3.0136**	
			(0.8925)	(1.4104)	
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{L(DNWR)})\mathbb{I}(\text{L}(e_{it}))$			3.3152***	1.7371*	1.5330
			(0.7181)	(1.0147)	(0.9640)
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{H}(\pi_{it}))$					-17.2008***
					(3.9467)
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))$					2.8577**
					(1.3907)
P-value from the test					
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H}(e_{it}))-\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))]=0$	0.01	0.11			
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))-\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{H}(\pi_{it}))]=0$	0.01	0.04			
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H}(e_{it}))-\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))]=0$			0.39	0.25	
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))-\mathbb{I}(\text{L(DNWR)})\mathbb{I}(\text{L}(e_{it}))]=0$			0.90	0.28	
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H}(e_{it}))-\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))]=0$					0.23
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{H}(\pi_{it}))-\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))]=0$					0.00
Observations	2,450	2,350	1,450	1,150	1,150
Period	1963 - 2018	1963 - 2018	1980-2018	1980-2018	1980-2018
Controls		Lagged variables		Lagged variables	Lagged variables
First-stage F	97.19	7.02	9.05	14.57	18.51
J Statistic	3.80	1.83	0.30	1.88	2.73
Jstat P value	0.28	0.61	0.96	0.60	0.74

Notes: The top panel reports the 2 year cumulative state-level multiplier along with associated standard errors below in parenthesis. The second panel shows p-values testing whether multipliers are statistically significantly different across states. Two instrumental variables are used for the estimation - sensitivity and Bartik instruments. The lagged variables are added as the control variables in Column 2, 4, and 5. The F-statistic corresponds to the Kleibergen-Paap rk Wald statistic. The J-statistics from overidentification tests are reported.

While considering two distinct states do not reveal significantly different effects of spending based on macroeconomic conditions, there is clearer evidence of state-dependence once we allow for interaction between employment, inflation, and DNWR. Table 7 shows three state dependent spending multipliers, allowing us to identify the source of recession - demand or supply shock driven. Since DNWR cannot be measured early in the sample period, we explore the size of the local spending multiplier based upon employment and inflation for the entire sample period. The spending multiplier is the highest when both employment and inflation are low, periods in which DNWR is most likely to bind (see Columns 1 and 2). This is in line with our theory that spending is more effective in a demand-driven recession (i.e. low employment and low inflation) than in a supply-driven recession (i.e. low employment and high inflation).

In order to test directly whether DNWR is a key mechanism in driving differences of spending multipliers across states of the economy, we use data on US-state-level degree of DNWR from 1980 to 2018. We find that the spending multiplier is highest for those US-state-year where slack period coincides with a high degree of DNWR (see Column 4 in Table 7). This finding supports our theory that the government spending is more effective in a recession when DNWR is a binding constraint, i.e. demand-driven recession.[38] The specification in Column 5 introduces four distinct states, allowing us to study differential impact on spending multipliers relying upon employment, inflation, and DNWR. It shows that the estimated effects of spending are largest during periods of high DWNR, low employment and low inflation (i.e. a demand-driven recession) and statistically different from the estimates for a high DNWR, low employment, and high inflation (i.e. a supply-driven recession) period. This result is in agreement with our theory that government spending is more effective in a demand-driven recession with binding DNWR than in a supply-driven recession.

We further consider alternative specifications, where we slice the data differently in Table 8. For the entire sample period, we find that the spending multiplier is the highest during a demand driven recession with low employment and inflation, without controlling for lagged variable (Column 1). Note that Column 2 specification results in very low first-stage F statistics. Controlling for lagged variables, the spending multipliers with high DNWR and low inflation is the only estimate statistically different from zero (Column 4). Column 5 shows that the spending multiplier in a demand-driven recession accompanied with high DNWR is the highest and this is the only estimate statistically significantly different from zero. The results from this alternative specifications also support our theory that government spending effectively raise output in a demand-driven recession when DNWR constraint binds.

7 Conclusion

We study the effectiveness of government spending depending on the source of the business cycle and the state of the economy. We first build a New Keynesian model with DNWR, featuring two different sources of the fluctuation: demand and supply shocks.

[38]These results are sensitive to controlling for lagged variables, and the estimates on different economic states seem to be similar to each other without controlling for lagged variables (Column 3).

The spending multipliers are different based on the nature of the recession. The simultaneous movement of nominal wage and price matters for DNWR constraint to have real consequences for labor. Regardless of the sources of fluctuation, nominal wages go down in recessions. Inflation rises in a demand-driven recession and falls in a supply-driven recession. Consequently, in a demand-driven recession, when nominal wage is constrained from downward adjustment, the fall in prices further prevent real wage from adjusting downwards, raising unemployment. As a result, government spending is more effective, since it 1) increases labor without raising wage and 2) raises inflation and the real interest rate to a less degree, leading to less crowing out effect. In a supply-driven recession, prices adjust upward while nominal wage is subject to DNWR, resulting in no real consequences on labor. To this end, the government spending multiplier in a demand-driven recession is much larger than in a supply-driven recession.

We provide empirical evidence that supports these theoretical results using US historical time series data and US state-level panel data. Based on the theory, a demand-driven recession is identified as a low-inflation-recession and a supply-driven recession as a high-inflation-recession. We find the spending multipliers are statistically significantly larger in a demand-driven recession than in a supply-driven recession, which is consistent with theoretical results. In addition, we show that the spending multiplier is higher in a US-state with a high degree of DNWR in a demand-driven recession.

Table 8: Alternative specification forstate dependent spending multipliers on employment, inflation, and DNWR: Three states

	(1) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(2) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(3) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(4) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$	(5) $\frac{Y_{it}-Y_{it-2}}{Y_{it-2}}$
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{H}(\pi_{it}))$	2.9832***	3.1799**	3.0015***	-0.4006	-0.5980
	(0.8684)	(1.4429)	(0.8589)	(3.2568)	(3.2693)
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))$	4.0830***	3.5161**			
	(1.0513)	(1.3239)			
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{H}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))$	0.7399	-0.7816			
	(1.0435)	(1.1212)			
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(\pi_{it}))$			4.6258***	2.1117*	
			(1.4356)	(1.1027)	
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{L(DNWR)})\mathbb{I}(\text{L}(\pi_{it}))$			4.1436***	1.3213	1.0312
			(1.4736)	(1.2231)	(1.4046)
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))$					2.6243**
					(1.2351)
$\frac{G_{it}-G_{it-2}}{G_{it-2}}\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{H}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))$					1.1163
					(1.5882)
P-value from the test					
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H}(\pi_{it})) - \mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))] = 0$	0.33	0.87			
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it})) - \mathbb{I}(\text{H}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))] = 0$	0.02	0.02			
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H}(\pi_{it})) - \mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(\pi_{it}))] = 0$			0.29	0.44	
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(\pi_{it})) - \mathbb{I}(\text{L(DNWR)})\mathbb{I}(\text{L}(\pi_{it}))] = 0$			0.69	0.38	
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H}(\pi_{it})) - \mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))] = 0$					0.38
$\frac{G_{it}-G_{it-2}}{G_{it-2}}[\mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{L}(e_{it}))\mathbb{I}(\text{L}(\pi_{it})) - \mathbb{I}(\text{H(DNWR)})\mathbb{I}(\text{H}(e_{it}))\mathbb{I}(\text{L}(\pi_{it}))] = 0$					0.38
Observations	2,450	2,350	1,450	1,150	1,150
Period	1963 - 2018	1963 - 2018	1980-2018	1980-2018	1980-2018
Controls		Lagged variables		Lagged variables	Lagged variables
First-stage F	17.32	2.71	28.40	21.54	17.87
J Statistic	2.72	3.99	1.83	3.27	2.78
Jstat P value	0.44	0.26	0.61	0.35	0.60

Notes: The top panel reports the 2 year cumulative state-level multiplier along with associated standard errors below in parenthesis. The second panel shows p-values testing whether multipliers are statistically significantly different across states. Two instrumental variables are used for the estimation - sensitivity and Bartik instruments. The lagged variables are added as the control variables in Column 2, 4, and 5. The F-statistic corresponds to the Kleibergen-Paap rk Wald statistic. The J-statistics from overidentification tests are reported.

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A.1 Appendix to Analytics of state-dependent government spending multipliers

An equilibrium is a set of stochastic processes $\{\lambda_t, c_t, w_t, mc_t, R_t, \pi_t, x_t^1, x_t^2, y_t, n_t, n_t^s, u_t, s_t, p_t^*\}_{t=0}^{\infty}$ satisfying:

$$\lambda_t = (c_t - \chi n_t^{\varphi})^{-\sigma} \tag{A.1}$$

$$\chi \varphi n_t^{s\varphi - 1} = w_t \tag{A.2}$$

$$\lambda_t = R_t \mathbb{E}_t \frac{\beta_{t+1}\lambda_{t+1}}{\pi_{t+1}} \tag{A.3}$$

$$W_t \geq \gamma W_{t-1}; w_t \geq \gamma \frac{w_{t-1}}{\pi_t} \tag{A.4}$$

$$(n_t^s - n_t)(w_t - \gamma \frac{w_{t-1}}{\pi_t}) = 0 \tag{A.5}$$

When DNWR does not bind ($w_t > \gamma \frac{w_{t-1}}{\pi_t}$), full employment is achieved, $n_t^s = n_t$ and $u_t = 0$. As opposed, if DNWR binds, that is, $w_t = \gamma \frac{w_{t-1}}{\pi_t}$, there is an excess supply of labor, $n_t^s > n_t$ and $u_t > 0$.

$$u_t = \frac{n_t^s - n_t}{n_t^s} \tag{A.6}$$

$$p_t^* = \frac{\theta}{\theta - 1} \frac{x_t^1}{x_t^2} \tag{A.7}$$

$$x_t^1 = y_t mc_t + \omega \mathbb{E}_t \beta_{t+1} \pi_{t+1}^{\theta} x_{t+1}^1 \tag{A.8}$$

$$x_t^2 = y_t + \omega \mathbb{E}_t \beta_{t+1} \pi_{t+1}^{\theta - 1} x_{t+1}^2 \tag{A.9}$$

$$mc_t = \frac{w_t}{A_t} \tag{A.10}$$

$$\pi_t = \left[\frac{1}{\omega} - \frac{1-\omega}{\omega} p_t^{*1-\theta}\right]^{\frac{1}{\theta-1}} \tag{A.11}$$

$$y_t = A_t n_t / s_t \tag{A.12}$$

$$y_t = c_t + g_t \tag{A.13}$$

$$s_t = (1-\omega) p_t^{*-\theta} + \omega \pi_t^{\theta} s_{t-1} \tag{A.14}$$

$$R_t = R(\frac{\pi_t}{\pi})^{\alpha_\pi} \tag{A.15}$$

, given exogenous stochastic processes $\{g_t, \beta_t, A_t\}_{t=o}^{\infty}$, which are following AR(1) processes specified as below:

$$\ln \frac{g_t}{g} = \rho^g \ln \frac{g_{t-1}}{g} + \epsilon_t^g \tag{A.16}$$

$$\ln \frac{\beta_t}{\beta} = \rho^\beta \ln \frac{\beta_{t-1}}{\beta} + \epsilon_t^\beta \tag{A.17}$$

$$\ln \frac{A_t}{A} = \rho^A \ln \frac{A_{t-1}}{A} + \epsilon_t^A \tag{A.18}$$

A.1.1 Derivation of IS-PC curves

We derive the IS and the Phillips curve (PC) summarizing equilibrium conditions, (A.1) ~ (A.15). To derive the IS equation, log-linearize both the monetary policy rule (A.15) and the household's intertemporal optimization equation (A.3). Combining the previous two equations yields

$$\widehat{\lambda_t} = \mathbb{E}_t\widehat{\lambda}_{t+1} + \alpha_\pi\widehat{\pi}_t - \mathbb{E}_t\widehat{\pi}_{t+1} + \mathbb{E}_t\widehat{\beta}_{t+1}. \tag{A.19}$$

, where hat variables stand for log-deviations from the steady state and the variable without time subscript represents its steady-state value. Find $\widehat{\lambda}_t$ by log-linearizing the marginal utility of consumption (A.1),

$$\widehat{\lambda_t} = -\frac{\sigma c}{c - \chi n^\varphi}\widehat{c}_t + \frac{\sigma\chi\varphi n^\varphi}{c - \chi n^\varphi}\widehat{n}_t. \tag{A.20}$$

Now let's find the steady-state values of variables. From the production function (A.12), we know that the steady state level of output y=A. Note that the steady-state value of s is zero under the zero inflation steady-state (Galí (2008)). By the market clearing condition (A.13), we find the steady-state consumption is then $c = y - g$. Define the steady-state government spending-to-output ratio as $s_g \equiv \frac{g}{y}$. Then, $c = (1 - s_g)A$. Assume the steady-state labor n equals to labor supply, n^s, which equals to 1. Using Equation (A.2) and (A.10), solve for the model-implied parameter χ assuring $n = 1$ as

$$\chi = \frac{w}{\varphi} = \frac{1}{\varphi} \times A \times mc = \frac{A}{\varphi}\frac{\theta - 1}{\theta}.$$

Substituting the steady-state values to the Equation (A.20) yields

$$\widehat{\lambda_t} = -\frac{\theta(1-s_g)}{\Psi}\widehat{c}_t + \frac{(\theta - 1)}{\Psi}\widehat{n}_t, \tag{A.21}$$

where $\Psi = \frac{\theta\varphi(1-s_g)-(\theta-1)}{\sigma\varphi}$. The log linearization of the market clearing condition (A.13) and the production function (A.12) leads

$$\widehat{c}_t = \frac{1}{1-s_g}\widehat{y}_t - \frac{s_g}{1-s_g}\widehat{g}_t \tag{A.22}$$

$$\widehat{y}_t = \widehat{a}_t + (\widehat{n}_t - \widehat{s}_t). \tag{A.23}$$

Galí (2008) shows that $\widehat{s}_t$ equals to zero up to a first-order approximation. Combining (A.19), (A.21), (A.22), and (A.23) yields the IS equation:

$$\widehat{y}_t = \mathbb{E}_t\widehat{y}_{t+1} - (\theta-1)(\widehat{a}_t - \mathbb{E}_t\widehat{a}_{t+1}) + \theta s_g(\widehat{g}_t - \mathbb{E}_t\widehat{g}_{t+1}) - \Psi(\alpha_\pi\widehat{\pi}_t - \mathbb{E}_t\widehat{\pi}_{t+1}) - \Psi\mathbb{E}_t\widehat{\beta}_{t+1} \tag{A.24}$$

where $\Psi = \frac{\theta\varphi(1-s_g)-\theta+1}{\sigma\varphi}$.

Now let's derive Phillips curve (PC). The PC can be written in two ways, depending upon whether DNWR binds or not. The first-order approximation of Equation (A.7) and (A.11) yields

$$\widehat{\pi}_t = \frac{(1-\omega)(1-\omega\beta)}{\omega}\widehat{mc}_t + \beta\mathbb{E}_t\widehat{\pi}_{t+1}, \tag{A.25}$$

where $\widehat{mc}_t$ takes two forms. When DNWR does not bind, full employment is acheived ($\widehat{n}_t = \widehat{n}_t^s$). Log-linearization of the Equation (A.2) under the full employment equilibrium yields $\widehat{w}_t = (\varphi-1)\widehat{n}_t$. From the Equation (A.10), we know that $\widehat{mc}_t = \widehat{w}_t - \widehat{a}_t$. Combining previous two equations with Equation (A.23) leads

$$\widehat{mc}_t = (\varphi-1)\widehat{y}_t - \varphi\widehat{a}_t. \tag{A.26}$$

Substituting (A.26) into (A.25) yields the PC curve under the full employment equilibrium:

$$\widehat{\pi}_t = \triangle(\varphi-1)\widehat{y}_t - \triangle\varphi\widehat{a}_t + \beta\mathbb{E}_t\widehat{\pi}_{t+1}, \tag{A.27}$$

where $\triangle = \frac{(1-\omega)(1-\omega\beta)}{\omega}$. When DNWR binds ($\gamma = 1$), we can re-write $\widehat{w}_t = \widehat{w}_{t-1} - \widehat{\pi}_t$. Then,

$$\widehat{mc}_t = \widehat{w}_{t-1} - \widehat{\pi}_t - \widehat{a}_t. \tag{A.28}$$

Substituting (A.28) into (A.25) yields the modified PC curve under the binding DNWR

$$(1+\triangle)\widehat{\pi}_t = \triangle[\widehat{w}_{t-1} - \widehat{a}_t] + \beta\mathbb{E}_t\widehat{\pi}_{t+1}. \tag{A.29}$$

A.1.2 Proof of analytical results

Proposition 1. In response to a preference shock, output ($\widehat{y}_t$) and inflation ($\widehat{\pi}_t$) co-move, and in response to a technology shock, output and inflation move in the opposite direction. That is,

$$\frac{\partial \widehat{y}_t}{\partial \widehat{\beta}_{t+1}} < 0; \frac{\partial \widehat{\pi}_t}{\partial \widehat{\beta}_{t+1}} < 0, \text{ and } \frac{\partial \widehat{y}_t}{\partial \widehat{a}_t} > 0; \frac{\partial \widehat{\pi}_t}{\partial \widehat{a}_t} < 0.$$

Proof. Let's consider two independent shock processes. The demand-driven business cycles follow ($\mathbb{E}_t \widehat{\beta}_{t+1} = \widehat{\beta}_{t+1}$, and $\mathbb{E}_t \widehat{\beta}_{t+2} = 0$) where $\mathbb{E}_t \widehat{\beta}_{t+1}$ is β_H in a demand-driven recession and $\mathbb{E}_t \widehat{\beta}_{t+1}$ is β_L in a demand shock-boom. The supply-driven business cycles are to follow ($\widehat{a}_t$=$\widehat{a}_t$, $\mathbb{E}_t \widehat{a}_{t+1}$=$\rho_a \widehat{a}_t$,and $\mathbb{E}_t \widehat{a}_{t+2}$=$\widehat{a}_{t+2}$) where $(\widehat{a}_t, \widehat{a}_{t+2}) = (a_H, a_L)$ in a supply-driven boom and $(\widehat{a}_t, \widehat{a}_{t+2}) = (a_L, a_H)$ in a supply-driven recession. Suppose that the market clearing solution takes the form:

$$\widehat{y}_t = A_y \widehat{g}_t + B_y \mathbb{E}_t \widehat{\beta}_{t+1} + C_y \widehat{a}_t + D_y \mathbb{E}_t \widehat{a}_{t+1} = A_y \widehat{g}_t + B_y \mathbb{E}_t \widehat{\beta}_{t+1} + C_y \widehat{a}_t + \rho_a D_y \widehat{a}_t$$

$$\widehat{\pi}_t = A_\pi \widehat{g}_t + B_\pi \mathbb{E}_t \widehat{\beta}_{t+1} + C_\pi \widehat{a}_t + D_\pi \mathbb{E}_t \widehat{a}_{t+1} = A_\pi \widehat{g}_t + B_\pi \mathbb{E}_t \widehat{\beta}_{t+1} + C_\pi \widehat{a}_t + \rho_a D_\pi \widehat{a}_t.$$

Given the assumptions on shock processes and government spending, the expected output and inflation are

$$\mathbb{E}_t \widehat{y}_{t+1} = A_y \mathbb{E}_t \widehat{g}_{t+1} + B_y \mathbb{E}_t \widehat{\beta}_{t+2} + C_y \mathbb{E}_t \widehat{a}_{t+1} + D_y \mathbb{E}_t \widehat{a}_{t+2} = \rho_a C_y \widehat{a}_t + D_y \widehat{a}_{t+2}$$

$$\mathbb{E}_t \widehat{\pi}_{t+1} = A_\pi \mathbb{E}_t \widehat{g}_{t+1} + B_\pi \mathbb{E}_t \widehat{\beta}_{t+2} + C_\pi \mathbb{E}_t \widehat{a}_{t+1} + D_\pi \mathbb{E}_t \widehat{a}_{t+2} = \rho_a C_\pi \widehat{a}_t + D_\pi \widehat{a}_{t+2}$$

Plug the projected solution into the IS curve (A.24) and Phillips curve (A.27) and solve for coefficients using the method of undetermined coefficients,

$$A_y = \frac{\theta s_g}{1 + \Psi \alpha_\pi \triangle(\varphi - 1)} > 0$$

$$A_\pi = \frac{\triangle(\varphi - 1)\theta s_g}{1 + \Psi \alpha_\pi \triangle(\varphi - 1)} > 0$$

$$B_y = \frac{\partial \widehat{y}_t}{\partial \widehat{\beta}_{t+1}} = -\frac{\Psi}{[1 + \Psi \alpha_\pi \triangle(\varphi - 1)]} < 0$$

$$B_\pi = \frac{\partial \widehat{\pi}_t}{\partial \widehat{\beta}_{t+1}} = -\frac{\Psi \triangle(\varphi - 1)}{[1 + \Psi \alpha_\pi \triangle(\varphi - 1)]} < 0$$

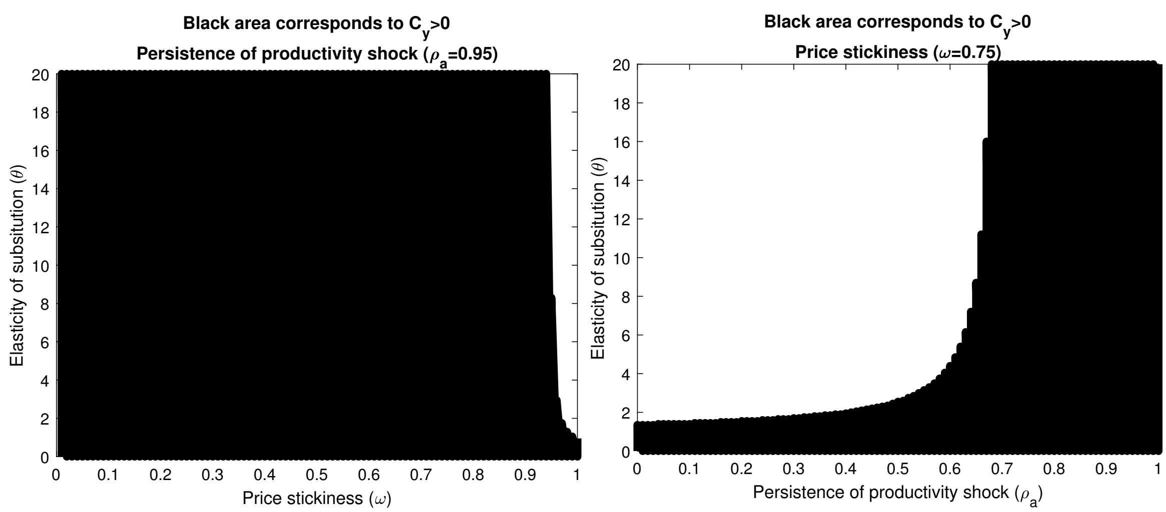
$$D_\pi = 0$$

$$D_y = 0$$

$$C_\pi = \frac{\partial \widehat{\pi}_t}{\partial \widehat{a}_t} = \frac{-\triangle}{(1-\beta\rho_a)}[\frac{(\varphi-1)(\theta-1)(1-\rho_a)(1-\beta\rho_a)+\varphi(1-\rho_a)(1-\beta\rho_a)}{(1-\rho_a)(1-\beta\rho_a)+\Psi(\alpha_\pi-\rho_a)\triangle(\varphi-1)}] < 0$$

$$C_y = \frac{\partial \widehat{y}_t}{\partial \widehat{a}_t} = \frac{-(\theta-1)(1-\rho_a)(1-\beta\rho_a)+\frac{\theta\varphi(1-s_g)-(\theta-1)}{\sigma\varphi}(\alpha_\pi-\rho_a)\frac{(1-\omega)(1-\omega\beta)}{\omega}\varphi}{(1-\rho_a)(1-\beta\rho_a)+\frac{\theta\varphi(1-s_g)-(\theta-1)}{\sigma\varphi}(\alpha_\pi-\rho_a)\frac{(1-\omega)(1-\omega\beta)}{\omega}(\varphi-1)}.$$

Figure A.1: Parameter space corresponding to positive C_y



Notes: The left panel shows the parameter space (θ, ω) that corresponds to positive C_y given the persistence of productivity shock is 0.95. The right panel shows the combination of (θ, ρ_a) that ensures positive C_y.

The sign of all coefficients except C_y is determinant under common parameter values.[1] However, depending on the parameter values, the sign of C_y changes. For example, for a high enough elasticity of substitution (θ) and price-stickiness parameter (ω) or a low enough persistence of productivity shock (ρ_a), C_y can be negative. To determine the sign of C_y, we fix the typical parameter values – the discount factor (β) is 0.99, the Frisch elasticity $(\frac{1}{\varphi-1})$ is 0.5, and Taylor coefficient on inflation (α_π) is 1.5. The steady-state government spending to output ratio s_g is calibrated to 0.2. The left panel of Figure A.1 shows the parameter space of θ and ω that corresponds to positive C_y, under the persistence productivity shock (ρ_a) being 0.95. C_y is positive for plausible parameter space. In New Keynesian literature, it is common to set ω as 0.75. The price rigidity of posted prices

[1]The elasticity of substitution parameter θ is greater than 1, the discount factor β is less than 1 and greater than zero. The government spending share in output, s_g is less than one. The intertemporal elasticity of substitution σ is assumed to be greater than one, while the frequency of price adjustment is ω is less than one. The Taylor coefficient on inflation is assumed to be higher than one.

varies from 0.45 to 0.73 from microdata literature (see Nakamura and Steinsson (2013)). The right panel of Figure A.1 shows the combination of θ and ρ_a that ensures positive C_y, when the price stickiness parameter, ω, is 0.75. For a high enough persistent productivity, we find that C_y is positive. To summarize, C_y is positive under the plausible parameter space. □

Proposition 2. In a model without DNWR, the government spending multiplier takes the same value M_y in expansion and recession states, i.e. is acyclical.

Proof. From the proof of Proposition 1, the government spending multiplier is

$$M_y \equiv \frac{dy}{dg} = \frac{\partial \widehat{y}_t}{\partial \widehat{g}_t}\frac{\overline{y}}{\overline{g}} = \frac{A_y}{s_g} = \frac{\omega\theta}{\omega + \Psi\alpha_\pi(1-\omega)(1-\omega\beta)(\varphi-1)} > 0$$

regardless of the shock processes and the state of the economy. □

Proposition 3. When DNWR binds in period t under the expectation of achieving full employment in period $(t+1)$, the spending multiplier is M_{DNWR} , which is bigger than M_y – the multiplier when DNWR does not bind.

Proof. Guess the solution that satisfies both IS curve (Equation (A.24)) and the modified Phillips curve (Equation (A.29)). Note that binding DNWR constraint leaves IS curve unchanged while PC changes. Let's first consider the demand-driven business cycle – ($\mathbb{E}_t\widehat{\beta}_{t+1} = \widehat{\beta}_{t+1}$, and $\mathbb{E}_t\widehat{\beta}_{t+2} = 0$). Then, the projected solution becomes

$$\widehat{y}_t = F_y\widehat{w}_{t-1} + H_y\widehat{g}_t + I_y\mathbb{E}_t\widehat{\beta}_{t+1} \tag{A.30}$$

$$\widehat{\pi}_t = F_\pi\widehat{w}_{t-1} + H_\pi\widehat{g}_t + I_\pi\mathbb{E}_t\widehat{\beta}_{t+1}. \tag{A.31}$$

Under the assumption that DNWR does not bind in period $(t+1)$, the expected output and inflation $\mathbb{E}_t\widehat{y}_{t+1}$ and $\mathbb{E}_t\widehat{\pi}_{t+1}$ become zero. Plug in suggested solutions (A.30) and (A.31) into IS curve (A.24) and the modified Phillips curves (Equation (A.29)) and find the coefficients using the method of undetermined coefficients,

$$F_y\widehat{w}_{t-1} + H_y\widehat{g}_t + I_y\widehat{\beta}_{t+1} = \theta s_g\widehat{g}_t - \Psi\alpha_\pi(F_\pi\widehat{w}_{t-1} + H_\pi\widehat{g}_t + I_\pi\widehat{\beta}_{t+1}) - \Psi\widehat{\beta}_{t+1}$$

$$(1+\triangle)(F_\pi\widehat{w}_{t-1} + H_\pi\widehat{g}_t + I_\pi\widehat{\beta}_{t+1}) = \triangle\widehat{w}_{t-1}$$

The multiplier in the demand-driven business cycle is

$$M^D_{DNWR} = \frac{dy}{dg} = \frac{\partial\widehat{y}_t}{\partial\widehat{g}_t}\frac{y}{g} = H_y\frac{1}{s_g} = \theta$$

, which is bigger than $M_y = \frac{\omega\theta}{\omega+\Psi\alpha_\pi(1-\omega)(1-\omega\beta)(\varphi-1)}$.

Now, let's consider the supply-driven business cycles following ($\widehat{a}_t$=$\widehat{a}_t$, $\mathbb{E}_t\widehat{a}_{t+1}$=$\rho_a\widehat{a}_t$,and $\mathbb{E}_t\widehat{a}_{t+2}$=$\widehat{a}_{t+2}$). Conjecture solution as,

$$\widehat{y}_t = O_y\widehat{w}_{t-1} + S_y\widehat{g}_t + U_y\widehat{a}_t + V_y\rho_a\widehat{a}_t \tag{A.32}$$

$$\widehat{\pi}_t = O_\pi\widehat{w}_{t-1} + S_\pi\widehat{g}_t + U_\pi\widehat{a}_t + V_\pi\rho_a\widehat{a}_t. \tag{A.33}$$

Under the assumption that DNWR does not bind in period $(t+1)$, the expected output and inflation are given by the full employment solution shown in the proof of Proposition 1, as below.

$$\mathbb{E}_t\widehat{y}_{t+1} = C_y\rho_a\widehat{a}_t + D_y\widehat{a}_{t+2} \tag{A.34}$$

$$\mathbb{E}_t\widehat{\pi}_{t+1} = C_\pi\rho_a\widehat{a}_t + D_\pi\widehat{a}_{t+2} \tag{A.35}$$

Combining the suggested solution ((A.32) and (A.33)) with the expected output and inflation ((A.34) and (A.35)) into the IS curve (A.24) and the modified Phillips curves (Equation (A.29)) brings

$$\begin{aligned} O_y\widehat{w}_{t-1} + S_y\widehat{g}_t + U_y\widehat{a}_t + V_y\rho_a\widehat{a}_t = {} & C_y\rho_a\widehat{a}_t + D_y\widehat{a}_{t+2} - (\theta-1)(\widehat{a}_t - \rho_a\widehat{a}_t) \\ & + \theta s_g\widehat{g}_t - \Psi\alpha_\pi(O_\pi\widehat{w}_{t-1} + S_\pi\widehat{g}_t + U_\pi\widehat{a}_t + V_\pi\rho_a\widehat{a}_t) + \Psi(C_\pi\rho_a\widehat{a}_t + D_\pi\widehat{a}_{t+2}) \end{aligned}$$

$$(1+\triangle)[O_\pi\widehat{w}_{t-1} + S_\pi\widehat{g}_t + U_\pi\widehat{a}_t + V_\pi\rho_a\widehat{a}_t] = \triangle[\widehat{w}_{t-1} - \widehat{a}_t] + \beta(C_\pi\rho_a\widehat{a}_t + D_\pi\widehat{a}_{t+2})$$

Using the undetermined coefficients method, we find $S_\pi = 0$ and $S_y = \theta s_g$. The output multiplier in the supply-driven business cycle is

$$M^S_{DNWR} = \frac{\partial\widehat{y}}{\partial\widehat{g}}\frac{y}{g} = S_y\frac{1}{s_g} = \theta.$$

Thus, we have shown that the multiplier is θ when DNWR binds (M_{DNWR}), regardless of the source of fluctuation. □

Lemma 1. Assume the economy is at the steady-state in period $t-1$, $\widehat{w}_{t-1} = 0$. In the presence of DNWR constraint ($\gamma = 1$), a positive discount factor shock or a negative productivity shock triggers DNWR constraint to bind and induces unemployment in period t.

Proof. Log-linearized DNWR constraint (Equation (A.4)) can be expressed as follows.

$$\widehat{w}_t \geq \gamma(\widehat{w}_{t-1} - \widehat{\pi}_t). \tag{A.36}$$

To show DNWR constraint binds in period t under the assumption that $\widehat{w}_{t-1} = 0$ and $\gamma = 1$, we have to show

$$\widehat{w}_t + \widehat{\pi}_t < 0. \tag{A.37}$$

Let's conjecture DNWR does not bind and $\widehat{n}_t = \widehat{n}_t^s$. Now check whether the conjecture holds, that is, Equation (A.36) is true. First, we obtain $\widehat{w}_t$ by combining two log-linearized Equation (A.2) and (A.12):

$$\widehat{w}_t = (\varphi - 1)(\widehat{y}_t - \widehat{a}_t).$$

From the proof of Proposition 1, we know that we can write $\widehat{y}_t$ and $\widehat{\pi}_t$ as follows.

$$\widehat{y} = A_y \widehat{g}_t + B_y \mathbb{E}_t \widehat{\beta}_{t+1} + C_y \widehat{a}_t + D_y \mathbb{E}_t \widehat{a}_{t+1} = B_y \mathbb{E}_t \widehat{\beta}_{t+1} + C_y \widehat{a}_t + \rho_a D_y \widehat{a}_t$$

$$\widehat{\pi} = A_\pi \widehat{g}_t + B_\pi \mathbb{E}_t \widehat{\beta}_{t+1} + C_\pi \widehat{a}_t + D_\pi \mathbb{E}_t \widehat{a}_{t+1} = B_\pi \mathbb{E}_t \widehat{\beta}_{t+1} + C_\pi \widehat{a}_t + \rho_a D_\pi \widehat{a}_t$$

Plug in $\widehat{y}_t$ and $\widehat{\pi}_t$ into the left-hand-side of inequality constraint (A.37)

$$\widehat{w}_t + \widehat{\pi}_t = (\varphi - 1)(B_y \mathbb{E}_t \widehat{\beta}_{t+1} + (C_y + \rho_a D_y - 1)\widehat{a}_t) + B_\pi \mathbb{E}_t \widehat{\beta}_{t+1} + (C_\pi + \rho_a D_\pi)\widehat{a}_t$$

In a demand-driven recession, where $\mathbb{E}_t \widehat{\beta}_{t+1} = \beta_H$ and $\widehat{a}_t = 0$,

$$\widehat{w}_t + \widehat{\pi}_t = ((\varphi - 1)B_y + B_\pi)\beta_H.$$

From the proof of Proposition 1, we know coefficients B_y and B_π are negative. Thus, for any positive discount factor shock, we know that

$$\widehat{w}_t + \widehat{\pi}_t < 0,$$

which contradicts the conjecture. Thus, we conclude that DNWR binds in response to a positive discount factor shock.

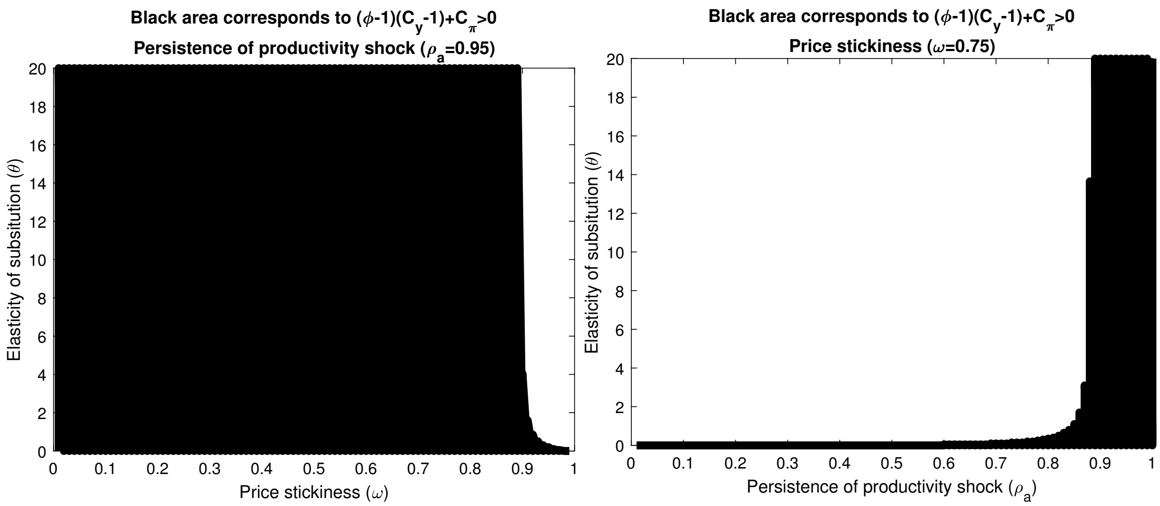
In a supply-driven recession, where $\widehat{a}_t = a_L$ and $\mathbb{E}_t \widehat{\beta}_{t+1} = 0$,

$$\widehat{w}_t + \widehat{\pi}_t = (\varphi - 1)((C_y + \rho_a D_y - 1)a_L) + (C_\pi + \rho_a D_\pi)a_L.$$

As $D_y = D_\pi = 0$, the conjecture that DNWR does not bind is not true if

$$\widehat{w}_t + \widehat{\pi}_t = [(\varphi - 1)(C_y - 1) + C_\pi]a_L < 0.$$

Figure A.2: Parameter space corresponding to positive $(\varphi - 1)(C_y - 1) + C_\pi$



Notes: The left panel shows the parameter space (θ, ω) that gives positive $(\varphi - 1)(C_y - 1) + C_\pi$ given the persistence of productivity shock is 0.95. The right panel shows the combination of (θ, ρ_a) that ensures positive $(\varphi - 1)(C_y - 1) + C_\pi$.

Based on the baseline parameter values[2], the black area in the left panel of Figure A.2 shows the combination of the elasticity of substitution (θ) and the price stickiness (ω) that satisfies

$$[(\varphi - 1)(C_y - 1) + C_\pi] > 0. \tag{A.38}$$

, where the persistence of the productivity shock ρ_a is 0.95. The right panel of FigureA.2 shows the combination of θ and ρ_a that satisfies Equation (A.38), when the price stickiness parameter, ω, is 0.75. Under the assumption of highly persistent productivity shock, we conclude that DNWR condition binds. □

Lemma 2. Assume the economy is at steady-state in period $t-1$, $\widehat{w}_{t-1} = 0$. In a demand-driven recession, if government spending is less than $\frac{\Psi}{\theta s_g}\beta_H \equiv c_d(\beta_H)$, DNWR constraint binds, and unemployment is greater than zero. Otherwise, DNWR is no longer a binding constraint, and unemployment is zero. In a supply-driven recession, if government spending is less than $c_s(a_L)$, DNWR constraint binds, and unemployment is greater than zero. Otherwise, DNWR is no longer a binding constraint, and unemployment is zero.

[2]The discount factor (β) is 0.99, the Frisch elasticity $(\frac{1}{\varphi - 1})$ is 0.5, and the Taylor coefficient on inflation (α_π) is 1.5.

Proof. Find the upper bound of nonzero $\widehat{g}_t$ that still violates DNWR condition, that is, $\widehat{w}_t < \gamma(\widehat{w}_{t-1} - \widehat{\pi}_t)$, or $\widehat{w}_t + \widehat{\pi}_t < 0$. With the nonzero government spending $\widehat{g}_t$, we can guess the solution as

$$\widehat{y} = A_y \widehat{g}_t + B_y \mathbb{E}_t \widehat{\beta}_{t+1} + C_y \widehat{a}_t + D_y \mathbb{E}_t \widehat{a}_{t+1} = A_y \widehat{g}_t + B_y \mathbb{E}_t \widehat{\beta}_{t+1} + C_y \widehat{a}_t + \rho_a D_y \widehat{a}_t$$

$$\widehat{\pi} = A_\pi \widehat{g}_t + B_\pi \mathbb{E}_t \widehat{\beta}_{t+1} + C_\pi \widehat{a}_t + D_\pi \mathbb{E}_t \widehat{a}_{t+1} = A_\pi \widehat{g}_t + B_\pi \mathbb{E}_t \widehat{\beta}_{t+1} + C_\pi \widehat{a}_t + \rho_a D_\pi \widehat{a}_t.$$

Then we can rewrite the left-hand-side of DNWR constraint (A.37)

$$\widehat{w}_t + \widehat{\pi}_t = (\varphi - 1)(A_y \widehat{g}_t + B_y \mathbb{E}_t \widehat{\beta}_{t+1} + (C_y + \rho_a D_y - 1)\widehat{a}_t) + A_\pi \widehat{g}_t + B_\pi \mathbb{E}_t \widehat{\beta}_{t+1} + (C_\pi + \rho_a D_\pi)\widehat{a}_t$$

In a demand-driven recession, where $\mathbb{E}_t \widehat{\beta}_{t+1} = \beta_H$ and $\widehat{a}_t = 0$,

$$\widehat{w}_t + \widehat{\pi}_t = ((\varphi - 1)A_y + A_\pi)\widehat{g}_t + ((\varphi - 1)B_y + B_\pi)\beta_H$$

Using the coefficients that we find from the proof of Proposition 1, we can rewrite the above equation as

$$\widehat{w}_t + \widehat{\pi}_t = (\frac{(\varphi - 1)\theta s_g (1 + \triangle)}{1 + \Psi \alpha_\pi \triangle (\varphi - 1)})\widehat{g}_t + (-\frac{\Psi(1 + \triangle)(\varphi - 1)}{[1 + \Psi \alpha_\pi \triangle (\varphi - 1)]})\beta_H$$

DNWR binds with non-zero government spending if $\widehat{w}_t + \widehat{\pi}_t < 0$, that is,

$$\frac{(\varphi - 1)\theta s_g (1 + \triangle)}{1 + \Psi \alpha_\pi \triangle (\varphi - 1)}\widehat{g}_t < \frac{\Psi(1 + \triangle)(\varphi - 1)}{1 + \Psi \alpha_\pi \triangle (\varphi - 1)}\beta_H$$

$$\widehat{g}_t < \frac{\Psi}{\theta s_g}\beta_H \equiv c_d(\beta_H)$$

In a supply-driven recession, where $\widehat{a}_t = a_L$ and $\mathbb{E}_t \widehat{\beta}_{t+1} = 0$, the left-hand-side of the inequality constraint (A.37) is

$$\widehat{w}_t + \widehat{\pi}_t = [(\varphi - 1)A_y + A_\pi]\widehat{g}_t + [(\varphi - 1)(C_y - 1) + C_\pi]a_L.$$

DNWR binds with non-zero government spending if $\widehat{w}_t + \widehat{\pi}_t < 0$, or, equivalently,

$$\widehat{g}_t < \frac{[(\varphi - 1)(C_y - 1) + C_\pi]}{[(\varphi - 1)A_y + A_\pi]}(-a_L) \equiv c_s(a_L) \tag{A.39}$$

Given the negative productivity shock, the right hand side of Equation (A.39) is positive. Note that we show both A_y and A_π are positive in the proof of Proposition 1 and $[(\varphi -$

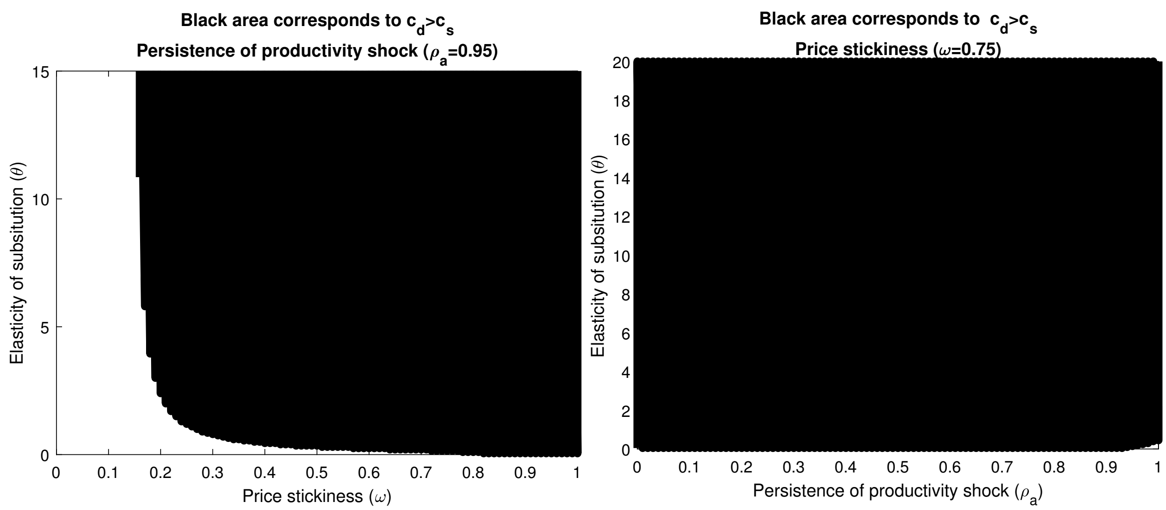
$1)(C_y - 1) + C_\pi]$ is positive from the proof of Lemma 1. □

Lemma 3. Under the assumption that $|\beta_H| = |a_L|$, it can be shown that $0 < c_s(a_L) < c_d(\beta_H)$. In other words, the government spending required to ensure DNWR is no longer binding is smaller in a supply driven recession than a demand driven recession.

Proof. For given $|\beta_H| = |a_L|$, we want to show that

$$\frac{[(\varphi - 1)(C_y - 1) + C_\pi]}{[(\varphi - 1)A_y + A_\pi]} < \frac{\Psi}{\theta s_g} \tag{A.40}$$

Figure A.3: Parameter space corresponding to $c_s(a_L) < c_d(\beta_H)$



Notes: The left panel shows the parameter space (θ, ω) that satisfies $c_s(a_L) < c_d(\beta_H)$ given the persistence of productivity shock is 0.95. The right panel shows the combination of (θ, ρ_a) that ensures $c_s(a_L) < c_d(\beta_H)$.

Based on the baseline parameter values, the black area in the left panel of Figure A.3 shows the combination of the elasticity of substitution (θ) and the price stickiness (ω) that satisfies Equation (A.40), where the persistence of the productivity shock ρ_a is 0.95. The right panel of Figure A.3 shows the combination of θ and ρ_a that satisfies Equation (A.40), when the price stickiness parameter, ω, is 0.75. We find the Equation (A.40) holds for most cases. □

A.2 Alternative preferences

Our baseline model considers GHH (Greenwood, Hercowitz, and Huffman (1988)) preferences which do not allow a wealth effect on labor supply. We relax this assumption and allow for wealth effects on labor supply by introducing KPR (King, Plosser, and Rebelo (1988)) preferences commonly used in the literature. In particular, the preferences take the following form,

$$U(c_t, n_t) = \frac{[c_t(1-\chi n_t^{\varphi})]^{1-\sigma}}{1-\sigma},$$

where we calibrate φ to ensure the same degree of Frisch elasticity of labor supply as in our baseline model.

Table A.1: Cumulative output and consumption multipliers by the source of fluctuation under KPR preferences

		Demand-driven business cycle				Supply-driven business cycle		
		Impact	4 quarters	20 quarters		Impact	4 quarters	20 quarters
				KPR preference				
Output	Expansion	0.485	0.485	0.485	Expansion	0.485	0.485	0.485
Multiplier	Recession	0.668	0.621	0.564	Recession	0.528	0.500	0.494
Consumption	Expansion	-0.515	-0.515	-0.515	Expansion	-0.515	-0.515	-0.515
Multiplier	Recession	-0.332	-0.379	-0.436	Recession	-0.472	-0.500	-0.506

Notes. This table reports the cumulative output and consumption multipliers in an expansion and a recession depending on the source of fluctuation. The cumulative output and consumption multipliers are calculated as $\Sigma_{i=0}^{i=k-1} \frac{\Delta y_{t+i}}{(1+r_{t+i})} / \Sigma_{i=0}^{i=k-1} \frac{\Delta g_{t+i}}{(1+r_{t+i})}$ and $\Sigma_{i=0}^{i=k-1} \frac{\Delta c_{t+i}}{(1+r_{t+i})} / \Sigma_{i=0}^{i=k-1} \frac{\Delta g_{t+i}}{(1+r_{t+i})}$, respectively, where Δ denotes the level differences of each variable with and without government spending and r_t is the real interest rate.

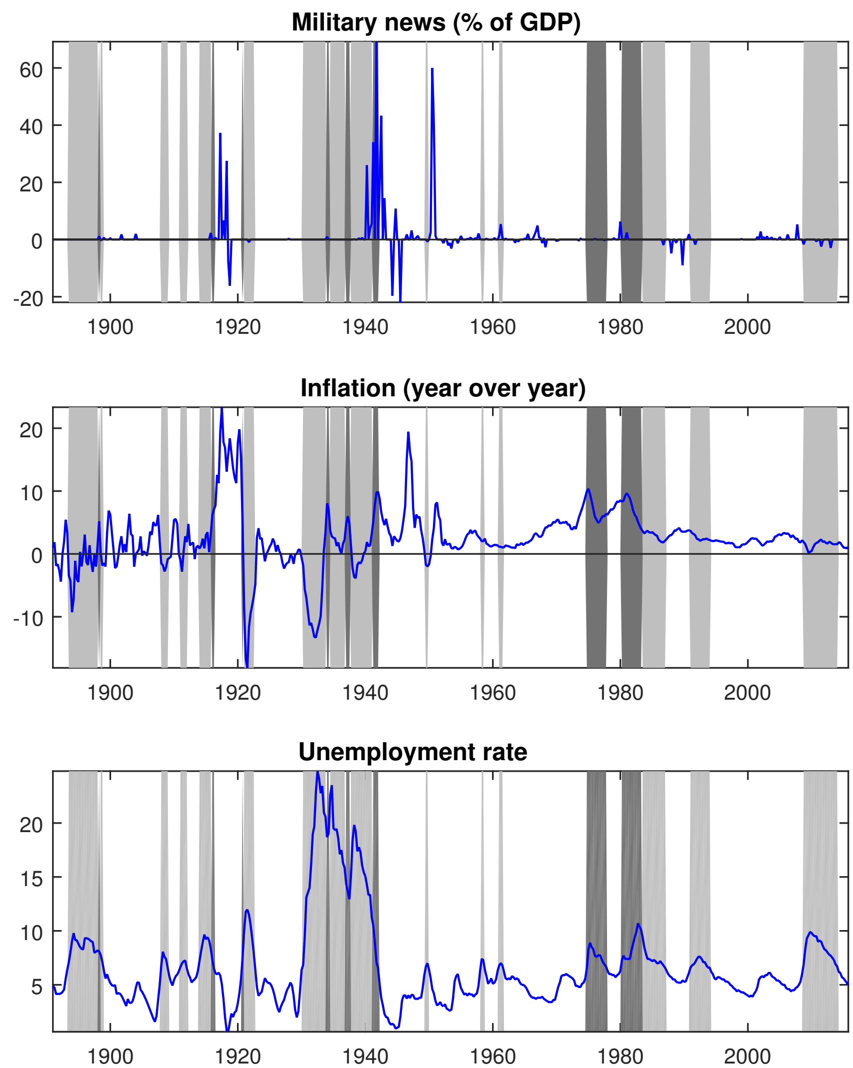
As Table A.1 shows, multipliers under these preferences are smaller across the board relative to GHH preferences.[3] This is because an increase in government spending under KPR preferences lead to negative wealth effects on the labor supply, as agents internalize higher taxes now or in the future. Consequently, this leads to a fall or a smaller rise in wages, and thus consumption is crowded out to a larger degree. Note also, that the multiplier in a demand-driven recession is larger than in an expansion (0.67 in a recession and 0.49 in an expansion under KPR preferences), but is much smaller in magnitude relative to under GHH preferences, (1.74 in a recession and 0.54 in an expansion under GHH preferences). This is because the labor supply curve shifts to the right, and overall weakens the effects of increased spending in reducing unemployment. Under these preferences, the DNWR binds in a supply-driven recession as well, leading to a larger output multiplier in a recession relative to an expansion. However, the difference in the multiplier across states is small and the multiplier in a supply driven recession is smaller than

[3] Under these preferences, we need to adjust the size of both the discount factor and productivity shock in order to generate the same size recession state.

the multiplier in a demand driven recession (0.53 versus 0.67, respectively). The intuition follows from Proposition 4 shown in Section 3.

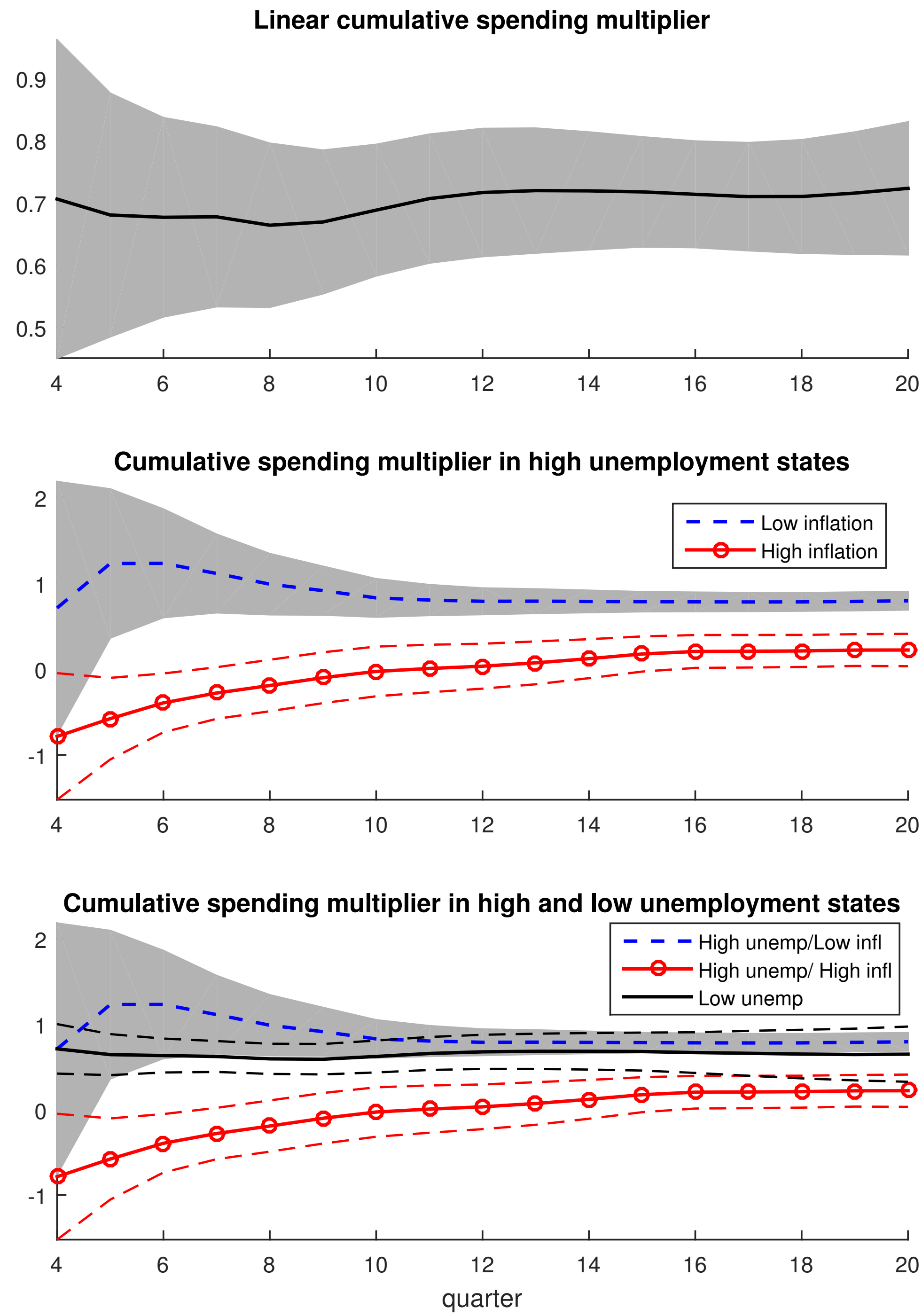
A.3 Appendix for Time series empirical evidence

Figure A.4: Inflation and unemployment states for U.S. historical data



Notes: Military spending news, year over year GDP deflator inflation rate and the unemployment rate. The shaded areas indicate periods when the unemployment rate is above the threshold of 6.5 percent. The light and dark gray areas correspond with periods where inflation is below and above 4 percent, respectively.

Figure A.5: State dependent fiscal multipliers: military news shocks



Notes: These figures show the cumulative multiplier for output in response to a military news shock from 4 quarters after the shock hits the economy. The top panel shows the cumulative multiplier in a linear model. The middle panel shows state-dependent multiplier in high unemployment/ low inflation (blue dashed) and high unemployment/ high inflation (red circles) states. The bottom panel shows the state dependent multipliers in low unemployment (black solid), high unemployment/ low inflation (blue dashed) and high unemployment/ high inflation (red circles) states. 95 percent confidence intervals are shown in all cases.

Table A.2: State-dependent fiscal multipliers for output: : military news shocks

	(1)	(2)	(3)	(4)	(5)	(6)
	2-year cumulative multiplier			4-year cumulative multiplier		
Σg_t	0.6637***			0.7134***		
	(0.0671)			(0.0436)		
$\Sigma g_t \times \mathbb{I}(L(u_t))$		0.6624***	0.6624***		0.7462***	0.7462***
		(0.1825)	(0.1825)		(0.2638)	(0.2635)
$\Sigma g_t \times \mathbb{I}(H(u_t))$		0.5190***			0.5621***	
		(0.0818)			(0.0757)	
$\Sigma g_t \times \mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))$			0.7804***			0.5802***
			(0.2631)			(0.1517)
$\Sigma g_t \times \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))$			0.2578***			0.5223***
			(0.0738)			(0.1529)
P-value from the test						
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))] = 0$		0.45			0.51	
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))] = 0$			0.71			0.57
$\Sigma g_t \times [\mathbb{I}(L(u_t)) - \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))] = 0$			0.01			0.45
$\Sigma g_t \times [\mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t)) - \mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))] = 0$			0.04			0.80
First-stage F statistics						
Linear	19.38			11.22		
$\mathbb{I}(L(u_t))$		15.36	14.93		5.06	4.92
$\mathbb{I}(H(u_t))$					2.75	
$\mathbb{I}(H(u_t))\mathbb{I}(L(\pi_t))$			22.81			9.82
$\mathbb{I}(H(u_t))\mathbb{I}(H(\pi_t))$			19.25			17.83
Observations	493	493	493	485	485	485

Notes: In this robustness check, we consider time-varying thresholds for both the unemployment rate and inflation. The time-varying trend is based on the HP filter with $\lambda = 10^6$, over a split sample, 1889–1929 and 1947–2015 and linearly interpolated for the small gap in trend unemployment between 1929 and 1947, in order to capture the evolution of the natural rate. The high inflation regime is one where inflation is above a HP filtered trend based on $\lambda = 1600$. The top panel panel reports the 2 and 4 year cumulative multiplier along with associated standard errors below. The second panel shows p-values testing whether multipliers are statistically significantly different across states. The last panel shows the first-stage Fstatistics for military news as an instrument at 2 and 4 year horizons for the given state.