Revisiting the Government Purchase Multiplier at the Zero Lower Bound

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Abstract

This paper revisits the magnitude of government purchase multiplier at the zero lower bound on nominal interest rates (ZLB). The novelty of this paper is that I compute the multiplier in a more realistic environment while keeping the model simple enough to identify mechanisms driving the result. In particular, I build on a standard New Keynesian model with occasionally binding ZLB and Rotemberg pricing with rebate, where the probability of hitting the ZLB and the government purchase shock are in line with the the US data. Moreover, I compute the multiplier in a state that mimics the Great Recession. The main findings of the paper include: (1) The multiplier is around 1.25; (2) Without occasionally binding ZLB or with transient government purchase or without rebate, the multiplier is around 1 or less; and (3) The multiplier is non-monotonic in the persistence of government purchase.

JEL classification: C61, C63, E52, E62.

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1. Introduction

The effectiveness of fiscal policy has received much attention from economists and policymakers since the target federal funds rate hit the ZLB in December 2007 and the conventional monetary policy became ineffective in stimulating economic activities. This paper revisits the magnitude of government purchase multiplier at the zero lower bound on nominal interest rates (ZLB). The novelty of this paper is that I compute the multiplier in a more realistic environment while keeping the model simple enough to identify mechanisms driving the difference between my results and those in the literature. Using more complex non-nested models would obscure the mechanisms.

Specifically, I build on a standard New Keynesian model with occasionally binding ZLB, where the probability of hitting the ZLB is in line withe the US data. In addition, I allow the price adjustment cost to be rebated to households so that it does not show up in the aggregate resource constraint. Finally, I compute the multiplier in a state that mimics the Great Recession and the government purchase shock follows an AR(1) process that fits the US data.

The main findings of the paper include: (1) The multiplier is around 1.25; (2) The multiplier is sensitive to all the features mentioned above. In the framework without occasionally binding ZLB or with transient government purchase or without rebate, the multiplier is around 1 or less; (3) The multiplier is non-monotonic in the persistence of government purchase while the economy is at the ZLB. The non-monotonicity becomes more pronounced when the expected ZLB duration increases.

The multiplier of 1.25 is higher than what is found by Boneva et al. (2016), even though the parameters used in this paper are very similar to those in their paper. They show that the government purchase multiplier is less than 1 when the expected

ZLB duration is 10 quarters. The discrepancy comes from three sources. First, I compute the multiplier based on the government purchase shock persistence of 0.86 that is consistent with the US data, while they use completely transient purchase. Intuitively, when the persistence of government purchase increases, future inflation is expected to be higher, leading to a smaller expected real interest rate *as long as the ZLB binds*. A smaller expected real interest rate would help promoting private consumption. This substitution effect would cause output to increase, which then causes the multiplier to increase.

Second, I allow for occasionally binding ZLB, while they use non-occasionally binding ZLB.[1] The additional uncertainty caused by occasionally binding ZLB makes recessions worse with more deflation in my model compared to their model. Therefore, government purchase is more effective and the multiplier is higher in my model than in their model.

Third, in my model but not in their model, the price adjustment cost is rebated to households so that it does not show up in the aggregate resources constraint. Without rebating, the price adjustment cost becomes part of aggregate demand. Under an adverse shock that pushes the economy to the ZLB with high deflation, this cost increases, helping raising the aggregate demand and mitigating the impact of of the shock. Hence, government purchase would be less effective. However, Eggertsson and Singh (2016) show that the price adjustment cost as a fraction of aggregate demand could be highly unrealistic at the ZLB in the model without rebate. In addition, Miao and Ngo (2016) recommend using Rotemberg pricing with rebates in order to generate results equivalent to the Calvo pricing.

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[1]The ZLB is assumed to bind initially. In the subsequent periods, there is a constant positive probability that it will bind again. However, when the ZLB does not bind, it will never bind again in the future. They pursue this approach to derive a closed-form equilibrium solution.

All the features mentioned above are important in producing a multiplier greater than 1. Without these characteristics the multiplier is around 1 or less. This is also the second finding of this paper.

The multiplier of 1.25 in this paper is smaller than those in Woodford (2011) and Christiano et al. (2011), where they find that the multiplier is around 2. Specifically, Woodford (2011) finds that the multiplier is around 2.3 while the economy is at the ZLB. Christiano et al. (2011) finds that the multiplier is in the range from 1.6 to 2.3. The reason for the difference is that the ZLB state is more persistent in their models than in my model. More importantly, they calibrate price rigidity such that the slope of the Phillips curve is larger in their models than in mine. In this paper the price adjustment parameter is calibrated such that the slope of the Phillips curve is in line with the US data, as noted by Boneva et al. (2016).

The last finding of the paper is an important complement to Woodford (2011), where he finds that the government purchase multiplier is monotonically decreasing in the persistence of government purchase. As seen in Figure 3 of Woodford (2011), when the ZLB is expected to bind for 10 periods, the multiplier is around 2.3 if the government purchase ends right after the ZLB stops binding. However, the multiplier decreases monotonically if the persistence of government purchase increases.

In this paper, the purchase multiplier is computed *while the economy is still at the ZLB*.[2] The multiplier first increases in the persistence, it then declines if the persistence is larger than a certain value. The intuition for the non-monotonicity is as follows: when the persistence of government purchase increases, future inflation is expected to be higher, leading to a smaller expected real interest rate *as long as*

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[2]The expected duration of ZLB remains unchanged when I change the persistence of government purchase because the magnitude of government purchase shock is small enough.

the ZLB binds. A smaller real interest rate would raise private consumption. This substitution effect would cause output and, as a result, the multiplier to increase. However, the government purchase also generates a negative wealth effect because of higher lump-sum taxes, which are levied to finance the government purchase. This negative wealth effect lowers private consumption. When the persistence is moderate, the positive substitution effect dominates the negative wealth effect, causing private consumption, output, and the multiplier to increase. However, if government purchase is too persistent, the negative wealth effect dominates the positive substitution effect so that consumption falls. Therefore, the multiplier starts decreasing when the persistence is sufficiently high.

This finding is also an important complement to Coenen et al. (2012), where they find that fiscal policy is most effective if it has moderate persistence and if monetary policy is accommodative. However, in their experiment, the monetary policy accommodation is not due to binding ZLB. Instead, they calibrate shocks such that the nominal interest rate remains 100 basis points above its steady state. Moreover, they did not compute their purchase multiplier in a state that mimics the Great Recession. Instead, they assume that the economy is initially in steady state. It is well-known that in a fully nonlinear model, the government purchase multiplier is state-dependent. In addition, the length of government purchase is imposed arbitrarily instead of following an AR(1) process.

My paper contributes to the literature investigating the effectiveness of fiscal policy at the ZLB based on standard New Keynesian models. A non-exhaustive list includes Christiano et al. (2011), Woodford (2011), Boneva et al. (2016), Eggertsson (2009), Eggertsson (2011), Eggertsson and Krugman (2012), Nakata (2016), and Hills and Nakata (2017). To save space, I do not discuss papers using non-nested estimated models or purely empirical models. I only discuss the difference between

this paper and some closely-related papers that use nested standard NK models, including Boneva et al. (2016), Woodford (2011) and Christiano et al. (2011), to identify clearly mechanisms driving the difference in results.

In terms of solution methods, my paper is most closely related to the papers by Judd et al. (2011), Fernandez-Villaverde et al. (2015), Gust et al. (2012), and Aruoba et al. (2018).[3] All these papers use global projection methods to approximate agents' decision rules in a DNK model with a ZLB constraint.[4] Fernandez-Villaverde et al. (2015) also studies the government purchase multiplier at the ZLB. However, they do not compute the multiplier at a state that mimics the Great Recession. It is well-known that economic responses and government purchase multipliers are state-dependent in a fully-nonlinear framework. In addition, they do not try to investigate the role of government purchase persistence.

The rest of the paper proceeds as follows. Section 2 describes the model. Section 3 shows the calibration and briefly explains the solution method. Section 4 discusses the main results of the paper. Section 5 presents some sensitivity analysis, and Section 6 concludes.

2. Model

The model I use in this paper is a standard dynamic New-Keynesian (DNK) model that features Rotemberg price setting with rebate and occasionally binding zero lower bound of nominal interest rate. I intentionally consider such a simple model so that I can understand clearly mechanisms driving the difference between my results and some notable results in the literature. Using more complex non-nested

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[3]In addition to the papers cited in the main text, an incomplete list of papers using nonlinear models with a ZLB constraint includes Wolman (2005), Nakata (2016), and Miao and Ngo (2016).

[4]Except for Aruoba et al. (2018), these papers solve the targeted inflation equilibrium only.

models would obscure the comparison.

The model consists of a continuum of identical households, a continuum of identical competitive final good producers, a continuum of monopolistically competitive intermediate goods producers, and a government (monetary and fiscal authorities).

2.1. Households

The representative household maximizes his expected discounted utility

$$E_1 \left\{ \sum_{t=1}^{\infty} \left(\Pi_{j=0}^{t-1} \beta_j \right) \left(\frac{C_t^{1-\gamma}}{1-\gamma} - \chi \frac{N_t^{1+\eta}}{1+\eta} \right) \right\} \tag{1}$$

subject to the budget constraint

$$P_t C_t + (1+i_t)^{-1} B_t = W_t N_t + B_{t-1} + \Pi_t + T_t, \tag{2}$$

where C_t is consumption of final goods, i_t is the nominal interest rate, B_t denotes one-period bond holdings, N_t is labor, W_t is the nominal wage rate, Π_t is the profit income, T_t is the lump-sum tax, and β_t denotes the preference shock. I assume that β_t follows an AR(1) process

$$\ln \left(\beta_t \right) = (1 - \rho_\beta) \ln \beta + \rho_\beta \ln \left(\beta_{t-1} \right) + \varepsilon_{\beta t}, \ \beta_0 = 1 \tag{3}$$

where $\rho_\beta \in (0,1)$ is the persistence of the preference shock and $\varepsilon_{\beta t}$ is the innovation of the preference shock with mean 0 and variance σ_β^2. The preference shock is a reduced form of more realistic forces that can drive the nominal interest rate to the ZLB. This setting is very common in the literature to model occasionally binding ZLB, for example see Aruoba et al. (2018), Nakata (2017), and Ngo (2014) among

others.[5]

The first-order conditions for the household optimization problem are given by

$$\chi N_t^\eta C_t^\gamma = w_t, \tag{4}$$

and

$$E_t \left[M_{t,t+1} \left(\frac{1+i_t}{1+\pi_{t+1}} \right) \right] = 1, \tag{5}$$

where $w_t = W_t/P_t$ is the real wage, $\pi_t = P_t/P_{t-1} - 1$ is the inflation rate, and the stochastic discount factor is given by

$$M_{t,t+1} = \beta_t \left(\frac{C_{t+1}}{C_t} \right)^{-\gamma}. \tag{6}$$

2.2. Final good producers

To produce the final good, the final good producers buy and aggregate a variety of intermediate goods indexed by $i \in [0,1]$ using a CES technology

$$Y_t = \left(\int_0^1 Y_t(i)^{\frac{\epsilon-1}{\epsilon}} \, di \right)^{\frac{\epsilon}{\epsilon-1}},$$

where ε is the elasticity of substitution among intermediate goods. The profit maximization problem is given by

$$\max \ P_t Y_t - \int_0^1 P_t(i) Y_t(i) \, di,$$

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[5]Another way to make the ZLB binding is to introduce a deleveraging shock as in Eggertsson and Krugman (2012) and Guerrieri and Lorenzoni (2011).

where $P_t(i)$ and $Y_t(i)$ are the price and quantity of intermediate good i. Profit maximization and the zero-profit condition give the demand for intermediate good i

$$Y_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t, \tag{7}$$

and the aggregate price level

$$P_t = \left(\int P_t(i)^{1-\epsilon} \, di\right)^{\frac{1}{1-\epsilon}}. \tag{8}$$

2.3. Intermediate goods producers

There is a unit mass of intermediate goods producers on $[0, 1]$ that are monopolistic competitors. Suppose that each intermediate good $i \in [0, 1]$ is produced by one producer using the linear technology

$$Y_t(i) = N_t(i), \tag{9}$$

where $N_t(i)$ is labor input. Cost minimization implies that each firm faces the same real marginal cost

$$mc_t = mc_t(i) = w_t. \tag{10}$$

2.4. Price setting

Following Rotemberg (1982), I assume that each intermediate goods firm i faces costs of adjusting prices in terms of final goods. In this paper, I use a quadratic adjustment cost function, which was proposed by Ireland (1997) and which is one of the most common functions used in the ZLB literature:

$$\frac{\varphi}{2}\left(\frac{P_t(i)}{P_{t-1}(i)} - 1\right)^2 Y_t,$$

where φ is the adjustment cost parameter which determines the degree of nominal price rigidity.[6] The problem of firm i is given by

$$\max_{\{P_t(i)\}} E_t \sum_{j=0}^{\infty} \left\{ M_{t,t+j} \left[\left(\frac{P_{t+j}(i)}{P_{t+j}} - mc_t \right) Y_{t+j}(i) - \frac{\varphi}{2} \left(\frac{P_{t+j}(i)}{P_{t+j-1}(i)} - 1 \right)^2 Y_{t+j} \right] \right\}$$
(11)

subject to its demand (7). In a symmetric equilibrium, all firms will choose the same price and produce the same quantity, i.e., $P_t(i) = P_t$ and $Y_t(i) = Y_t$. The optimal pricing rule then implies that

$$(1 - \varepsilon + \varepsilon w_t - \varphi \pi_t (1 + \pi_t)) Y_t + \varphi E_t [M_{t,t+1} \pi_{t+1} (1 + \pi_{t+1}) Y_{t+1}] = 0.$$
(12)

2.5. Monetary and fiscal policies

The central bank conducts monetary policy by setting the interest rate using a simple Taylor rule, subject to the ZLB condition:

$$\frac{1 + i_t}{1 + i} = \max \left\{ \left(\frac{GDP_t}{GDP} \right)^{\phi_y} \left(\frac{1 + \pi_t}{1 + \pi} \right)^{\phi_\pi}, \frac{1}{1 + i} \right\}$$
(13)

where $GDP_t \equiv C_t + G_t$ denotes the gross domestic product (GDP) and GDP, π, and i denote the steady state GDP level, the targeted inflation rate, and the steady-state nominal interest rate, respectively.

Following Fernandez-Villaverde et al. (2015), Gust et al. (2017), and Aruoba et al. (2018), I assume that the government consumes a stochastic fraction of GDP and runs a balanced budget and raises lump-sum taxes to finance the government

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[6]For example, see Nakata (2016) and **?** among others. It would also be interesting to compare the time-dependent Calvo price setting to another state-dependent price setting as in Dotsey et al. (1999) at the ZLB.

purchase, which is given by

$$G_t = S_g g_t GDP_t,$$

where S_g denotes the steady state share of the government purchase and g_t denotes the government purchase shock that follows an AR(1) process:

$$\ln g_t = \rho_g \ln g_{t-1} + \varepsilon_{gt},$$

where $\rho_g \in (0, 1)$ is the persistence parameter and ε_{gt} is the innovation with mean 0 and variance σ_g^2.[7]

Some researchers such as Woodford (2011) and Boneva et al. (2016) model the ZLB following a two-state Markov process with one absorbing state, which is the non-ZLB state. They also model government purchase being perfectly correlated with the ZLB state. The main purpose is to derive a closed form solution for the policy function and the purchase multiplier. The trade-off is that they cannot study the implications of occasionally-binding ZLB and government purchase persistence on the multiplier while the economy is at the ZLB. In this paper, I am able to study the implications because I keep the shock driving the ZLB and the government purchase shock independent and flexible.

2.6. Equilibrium systems

With the Rotemberg price setting, the aggregate output satisfies

$$Y_t = N_t. \tag{14}$$

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[7]I have also modeled government purchase G_t, instead g_t, following an AR(1) process. The main results and insights are robust. To save space, I do not report them here. However, the additional results are available upon request.

It is important to note that in this paper, I assume the price adjustment cost is rebated to the household so that it does not show up in the resource constraint, which is given by

$$C_t + G_t = Y_t. \tag{15}$$

Miao and Ngo (2016) recommend that ZLB research should use either Calvo pricing or Rotemberg pricing with rebate as in this paper. The reason is that the model using Rotemberg pricing with rebate produces very similar results with Calvo pricing and can avoid a highly unrealistic price adjustment cost at the ZLB, as noted in Eggertsson and Singh (2016).

The equilibrium system for the Rotemberg model consists of a system of six nonlinear difference equations (4), (5), (12), (13), (14), (15) for six variables w_t, C_t, i_t, π_t, N_t, and Y_t.

3. Calibration and solution method

The quarterly subjective discount factor β is set at 0.997 such that the annual real interest rate is 1.2%, as in Christiano et al. (2011) and Boneva et al. (2016). The constant relative risk aversion parameter γ is 1, corresponding to a log utility function with respect to consumption. This utility function is commonly used in the business cycles literature. The labor supply elasticity with respect to wages is set at 1, or $\eta = 1$, as in Christiano et al. (2011). The value of χ is calibrated to obtain the steady state faction of working hours of 1/3. The elasticity of substitution among differentiated intermediate goods ϵ is 7.66, corresponding to a 15% net markup that is in the range found by Diewert and Fox (2008). This value is also popular in the literature (e.g. Boneva et al. (2016)).

I set the price adjustment cost parameter in the Rotemberg model $\varphi = 495.8$ as

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Table 1: CALIBRATION

Symbol	Description	Values
β	Quarterly discount factor	0.997
γ	CRRA parameter	1
η	Inverse labor supply elasticity	1
ε	Monopoly power	7.66
φ	Price adjustment cost parameter in the Rotemberg model	495.8
π	Inflation target	0
ϕ_π	Weight of inflation target in the Taylor rule	1.75
ϕ_y	Weight of output target in the Taylor rule	$\frac{0.5}{4}$
S_g	Share of the government purchase at the steady state	0.2
σ_β	Standard deviation of preference innovations	$\frac{0.1}{100}$
ρ_β	AR-coefficient of preference shocks	0.85
σ_g	Standard deviation of government purchase innovations purchase shocks	$\frac{0.3}{100}$
ρ_g	AR-coefficient of government purchase shocks	0.86

in Boneva et al. (2016). This value, together with the other parameters, implies that the slope of the Phillips curve is 0.0269, which is within the range estimated by Ball and Mazumder (2011) for the US using the 1985:q1-2007:q4 data.

I set the parameters in the Taylor rule at $\phi_\pi = 1.75$ and $\phi_y = 0.25$, which are close to the estimates by Gust et al. (2017). The conventional average share of the government purchase in output $S_g = 0.20$, as in Christiano et al. (2011) among others.

Based on my empirical assessment using the US data in the appendix, I set the persistence of government purchase shock $\rho_g = 0.86$ and the standard deviation for the shock innovations $\sigma_g = \frac{0.3}{100}$. This persistence value is considered as the benchmark of the paper.

The most important parameters left to calibrate are those regarding the prefer-

ence shock. Following Gust et al. (2017), I set the persistence of preference shock at 0.85. I set the standard deviation for prefence innovations $\sigma_\beta = \frac{0.1}{100}$ so that the unconditional probability of hitting the ZLB is around 17%, which is consistent with the recent US data.[8]

In terms of solution, I use projection methods, which is similar to Miao and Ngo (2016) In particular, I approximate the expectations as a function of state variables using a finite element method called the linear spline interpolation (Judd (1998) and Miranda and Fackler (2002)). The nominal interest rate is always determined by equation (13) at every state, in or out of the set of collocation nodes. The main advantage of this approach is that I do not have to worry about the kink when the ZLB starts binding. Furthermore, expectations can smooth out the kink. The detailed algorithm and computation errors can be found in Miao and Ngo (2016).

4. Results

I compute the government purchase multiplier under 1% government purchase shock for a state that mimics the Great Recession in the following way: (i) the ZLB is expected to bind for 10 periods, which is consistent with the ZLB literature regarding the Great Recession, see Woodford (2011);[9]; (ii) the real GDP falls by about 6.5%; (iii) the inflation rate is around -3%. The fall of GDP and inflation are consistent with the US data, see the Appendix for the output gap series and inflation series. During the Great Recession, the US output fell about 6.5%. Although the

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[8]See Appendix A for my calculation of the unconditional probability of hitting the ZLB using different methods.

[9]Although this expected ZLB duration of 10 periods is debatable, the ZLB literature tends to use this number, see Woodford (2011), Boneva et al. (2016) and Christiano et al. (2011). I use this number so that my result is more comparable to those in the literature. In the Sensitivity Analysis section, I examine the impact of different expected ZLB duration on the multiplier.

data show that the annualized inflation rates was -14% at the trough of the Great Recession, it is more reasonable to use a conservative value of -3% or less.[10]

I compute the purchase multiplier based on conventional impulse responses of GDP and government purchase.[11] In particular, I first compute the responses of GDP and government purchase, $(GDP_t^1, G_t^1)_{t=1}^T$, under only adverse preference shock that puts the economy at a state similar to the Great Recession. While the preference shock dies out according its motion equation, the other shocks (for both present and future) are imposed at the median values. I then compute the responses of GDP and government purchase, $(GDP_t^2, G_t^2)_{t=1}^T$, under both the preference shock and additional 1% government purchase shock. Afterward, I compute the conventional impulse response functions (IRF) as $IRF_t^X = X_t^2 - X_t^1$, where $X = (GDP, G)$. The (impact) multiplier is computed using the following formula.[12,13]

$$m_{Impact}^{ZLB} = \frac{IRF_1^{GDP}}{IRF_1^G}. \tag{16}$$

For comparison, I also compute the multiplier when the ZLB is not binding. In

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[10]See the Appendix for more discussion about the US GDP and inflation over time.

[11]Note that I am aware of the fact that the policy functions are nonlinear, so the impulse response functions are both shock and state dependent. Therefore, in the Sensitivity Analysis section I also compute the multiplier based on generalized impulse response functions (GIRFs), as described in Koop et al. (1996) and in Miao and Ngo (2016). The results based on GIRFs are quite similar to those based on the conventional IRF explained in this section.

[12]I also compute the results under $0.5\%, 1\%, 2\%$, and 5% government purchase shocks. The additional results are presented in the Sensitivity Analysis section and consistent with the finding in Fernandez-Villaverde et al. (2015) and Christiano et al. (2011) that the larger the government purchase, the smaller the purchase multiplier. However, the difference is very small for shocks in the range of 1-3%.

[13]There are other multipliers including cumulative multipliers and present value multipliers. However, most of the literature compute and report impact multipliers. Therefore, in this section I use impact multipliers for meaningful comparison. In the Sensitivity Analysis Section, I compute and report both cumulative and present multipliers.

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particular, I compute the multiplier at the steady state, which is also the median state.

The main result is that the government purchase multiplier is 0.6 when the ZLB is not binding and 1.25 when the ZLB is binding. It is well-known in the literature that outside the ZLB, higher government purchase would cause private consumption to decrease. This decrease occurs because an increase in government purchase will cause higher prices and inflation. Under the Taylor principle, the central bank would raise the nominal interest rate more than the increase in inflation, resulting in an increase in the real interest rate that lowers private consumption. That is why the multiplier is less than one. However, when the nominal interest reaches the ZLB, the monetary authority can not lower the nominal interest rate further. An increase in government purchase will not raise the real interest rate. In fact, it raises expected inflation, lowering the expected real interest, helping raising private consumption. Therefore, the multiplier is greater than one.

4.1. Why is my result different from those in the recent literature?

Boneva et al. (2016) find that the government purchase multiplier is less than 1 under the parameterization which is very similar to ours.[14] There are three main reasons that explain the discrepancy.[15] The first main reason is that the government purchase in their paper is completely transient. In their model setting, they are not able to impose an independent and persistent government purchase shock. On the contrary, I am able to implement that in my model setting. To see the impact of government purchase persistence on the multiplier, I resolve the model and compute the multiplier for many different values of persistence in the range $[0, 0.94]$. The

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[14]They also assume the ZLB is expected to bind for 10 periods as in my paper.

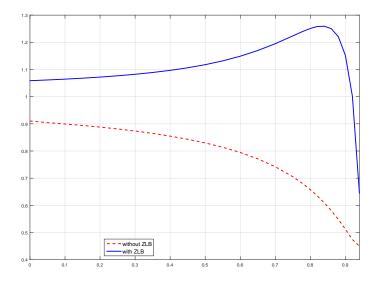[15]The comparisons of non-nested estimated models obscure.

Figure 1: Government purchase multipliers. In the case at the ZLB, the ZLB binds for 10 periods on average.

results are presented in Figure 1.

As seen from Figure 1, at the benchmark persistence $\rho_g = 0.86$, the multiplier is around 1.25. However, when the purchase is completely transient, $\rho_g = 0$, the multiplier is only 1.07, which is still greater than the value in their paper.

The second main reason is that in my setting the ZLB is occasionally binding. Many papers in the literature (e.g., Boneva et al. (2016), Christiano et al. (2011), and Eggertsson and Singh (2016)) pursue the non-occasionally binding ZLB (or perfect foresight) approach.[16] Specifically, they assume that the ZLB shock follows a two-state Markov chain, where one state is an absorbing state. The economy is assumed

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[16]This approach is extremely useful in deriving a closed-form equilibrium solution that can provide crystal insights on the roles of many important parameters on the multiplier. However, this approach has its own drawbacks, including: (i) not being able to study independent and flexible shock processes; and (2) not being able to study the impact of additional uncertainty caused by occasionally binding ZLB on the multiplier.

to be initially in the recession state with binding ZLB. There is a positive probability that the economy will stay there in the next period. With the remaining probability, the economy will move to the normal state with positive interest rate. When the ZLB has escaped, it will never come back. In their models, the expectation of binding ZLB duration is mainly determined by the exogenous probability of remaining at the ZLB state. In my model setting, the expected duration is determined by both the persistence and the magnitude of preference shock. As explained above, I have computed the government purchase multiplier at a state that mimics the Great Recession where the ZLB is expected to bind 10 periods, as in Boneva et al. (2016).

The dot-dashed black line in Figure 2 shows the multiplier for the case of perfect foresight, which is very different from the benchmark results with occasionally binding ZLB. Specifically, when the persistence is 0.86, the occasionally binding ZLB method generates the multiplier of 1.25, while the non-occasionally binding (perfect foresight) method produces the multiplier of approximately 1. This occurs because the recession is worse under the occasionally binding ZLB due to the possibility of the ZLB coming back. Therefore the substitution effect caused by persistent purchase shock is larger, and the multiplier is bigger under occasionally binding ZLB.

The last main reason is that in my model the price adjustment cost is rebated to household so that it does not show up in the aggregate resource constraint. Without rebating, the price adjustment cost becomes part of aggregate demand. Under an adverse shock that pushes the economy to the ZLB with high deflation, this cost increases, helping raising the aggregate demand and mitigating the impact of of the shock. Hence, government purchase would be less effective. However, as explained by Eggertsson and Singh (2016), without rebating the price adjustment cost could account for most real output when the ZLB binds with large deflation, which is highly unrealistic. Importantly, rebating will make the Rotemberg price setting similar to
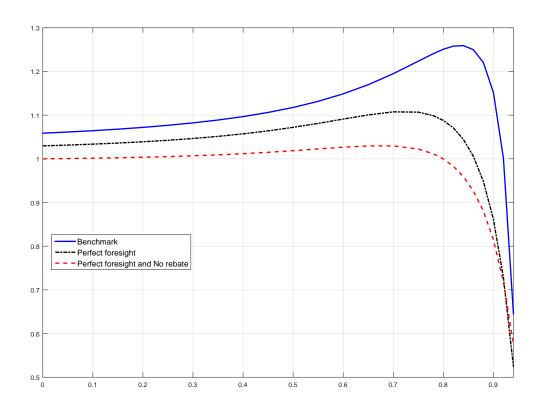
Figure 2: Government purchase multipliers at the ZLB with different purchase persistence. The ZLB binds for 10 periods on average.

the Calvo price setting, as noted by Miao and Ngo (2016).

The dashed red line of Figure 2 shows the multiplier for the case with both aggregate resource cost and perfect foresight. As seen from this figure, allowing aggregate resource cost to price adjustments (the case with perfect foresight and without rebate) causes the multiplier to decline further to 0.9 when the government purchase persistence is 0.86. This less-than-one multiplier is consistent with the result in .

Woodford (2011) and Christiano et al. (2011) find that the multiplier is around 2. Specifically, Woodford (2011) finds that the multiplier is around 2.3 while the economy is at the ZLB. Christiano et al. (2011) finds that the multiplier is in the range from 1.6 to 2.3. The main reason for the difference between my results and theirs is that the ZLB state is more persistent in their models than in my model. In addition, they calibrate price rigidity such that the slope of the Phillips curve is larger in their models, as noted by Boneva et al. (2016). In this paper I calibrate the price adjustment parameter such that the slope of the Phillips curve is in line with the US data, see the calibration subsection for more detail. It is well-known that the larger the slope, the larger the increase in inflation under an increase in government purchase (and output gap), leading to a larger decline in real interest rate if the nominal interest is stuck at the ZLB. The larger decline in the real interest rate leads to a larger increase in consumption (and output), making the government purchase multiplier larger.

4.2. Other important results

The multiplier at the ZLB is non-monotonic in the persistence of government purchase, as shown by the solid blue line in Figure 1 and the lines in Figure 2. This finding is an important complement to Woodford (2011), where he finds that

the government purchase multiplier is monotonically decreasing in the persistence of government purchase after the financial disturbance ends and the ZLB is no longer binding. As seen in Figure 3 of Woodford (2011), when the ZLB is expected to bind for 10 periods, the multiplier is around 2.3 if the government purchase ends right after the ZLB stops binding. However, the multiplier decreases monotonically if the persistence of government purchase increases. In this paper, the non-monotonic relationship between government purchase and the multiplier occurs *while the economy is at the ZLB*.

The intuition for the non-monotonicity is as follows: when the persistence of government purchase increases, future inflation is expected to be higher, leading to a smaller expected real interest rate *as long as the ZLB binds*. A smaller real interest rate would raise private consumption. This substitution effect causes output and, as a result, the multiplier to increase. However, government purchase also generates a negative wealth effect because of higher lump-sum taxes, which are levied to finance the government purchase. This negative wealth effect lowers private consumption output. When the persistence is moderate, the positive substitution effect dominates the negative wealth effect, causing the multiplier to raise. However, if government purchase is too persistent, the negative wealth effect dominates the positive substitution effect so that consumption falls. Therefore, the multiplier starts decreasing when the persistence is sufficiently high. It can be smaller than one if the persistence is greater than 0.9.

This finding is also an important complement to Coenen et al. (2012), where they find that fiscal policy is most effective if it has moderate persistence and if monetary policy is accommodative. In their experiments, the monetary policy accommodation is not due to binding ZLB. Instead, they calibrate shocks such that the nominal interest rate remains 100 basis points above its steady state. Moreover, they did not
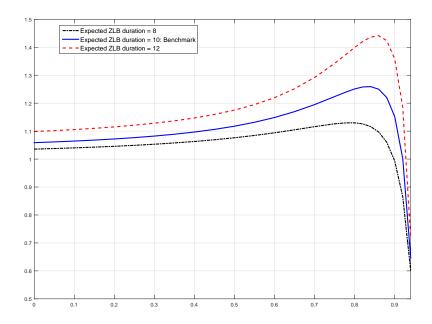
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Figure 3: Government purchase multipliers the ZLB. The ZLB binds for 8, 10, and 12 periods on average.

compute their purchase multiplier in a state that mimics the Great Recession. Instead, they assume that the economy is initially in steady state. It is well-known that in a fully nonlinear model, the government purchase multiplier is state-dependent. In addition, the length of government purchase is imposed arbitrarily instead of following an AR(1) process.

5. Sensitivity analysis

5.1. Multiplier and ZLB duration

The expected ZLB duration at the onset of the Great Recession is debatable. Therefore, it is useful to analyze the impact of expected ZLB duration on the effectiveness of government purchase. To this end, I compute the multiplier at different

ZLB states where the expected ZLB duration varies. The results are presented in figure 3. From this figure, when the expected ZLB duration increases, the multiplier increases. In particular, at the benchmark government purchase persistence of 0.86, the multiplier is 1.45 if the ZLB is expected to bind for 12 periods. This value is greater than 1.25 under the benchmark case with average 10-period binding ZLB. The results are consistent with the ZLB literature. See Fernandez-Villaverde et al. (2015) and Woodford (2011).

It is interesting to note that (i) the non-monotonicity becomes more pronounced when the expected ZLB duration increases; and (ii) there is not any discontinuity in the impact multiplier when the expected ZLB duration is greater than 10 as found in some papers, including Boneva et al. (2016). The difference comes from the settings of the two models. In their model, the expected ZLB duration is determined by the exogenous probability of staying at the ZLB regime, while in this paper the expected ZLB duration is determined by both the magnitude of the preference shock and the persistence of the shock.

5.2. Multiplier and price adjustment costs

Figure 4 shows that the government purchase multiplier and the price adjustment cost parameter ϕ are negatively correlated. When the price adjustment cost parameter decreases, the multiplier increases. The intuition is straight-forward. A smaller adjustment cost parameter leads to more price flexibility. As a result, inflation increases more under an increase in government purchase, leading to a larger decline in the real interest rate if the nominal interest rate remains at the ZLB. This larger decrease in the real interest rate causes consumption and output to increase more. Thus, the government purchase multiplier is greater.
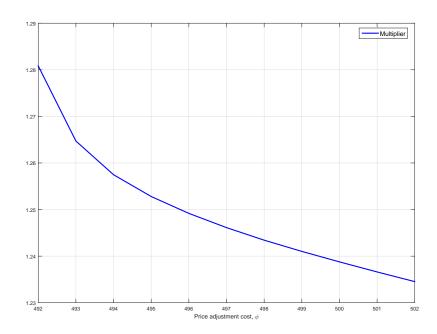
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Figure 4: Government purchase multipliers at the ZLB and price adjustment costs. The ZLB binds for 10 periods on average.
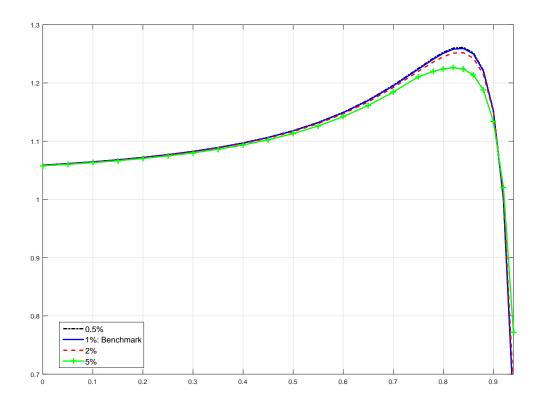
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Figure 5: Government purchase multipliers at the ZLB under various values of initial government purchase shock. The ZLB binds for 10 periods on average.

5.3. Magnitude of government purchase shock

Because of the nonlinear policy functions, it is likely that the marginal effect of government purchase shock and, as a result, the purchase multiplier also depend on the magnitude of the initial shock. In this subsection, I compute and plot the purchase multiplier under 0.5%, 1%, 2%, and 5% shocks to government purchase. The results are presented in figure 5.

As seen from figure 5, under the benchmark purchase persistence of 0.86, the larger the initial government purchase shock, the smaller the multiplier at the ZLB.

However, the results are quite robust when the magnitude of the purchase shock is around 1%. The decline of the multiplier in the magnitude of initial purchase shock is consistent with the finding in Fernandez-Villaverde et al. (2015) and Christiano et al. (2011).

5.4. Cumulative purchase multiplier

Although the impact multiplier is commonly used in the literature of ZLB and fiscal policy, I would like to see if the results of the paper are robust if I use the present-value multiplier. The present value multiplier is computed using the following formula:

$$m_{PresentValue}^{ZLB} = \left(\frac{\sum_{t=1}^{T} \left(\Pi_{j=0}^{t-1} \beta_j \right) \left(GDP_t^2 - GDP_t^1 \right)}{\sum_{t=1}^{T} \left(\Pi_{j=0}^{t-1} \beta_j \right) \left(G_t^2 - G_t^1 \right)} \right) \tag{17}$$

where $(GDP_t^1, G_t^1)_{t=1}^{T}$ denotes the responses of GDP and purchase under only preference shock; $(GDP_t^2, G_t^2)_{t=1}^{T}$ denotes the responses of GDP and purchase under both preference and government purchase shock.[17]

The present value multiplier is presented together with the impact multiplier in figure 6 for the benchmark case and for the case with perfect foresight and no rebate. We can see that the non-monotonic relationship between present value multiplier and purchase persistence still holds. At the persistence of 0.86, the present value multiplier is still above 1. However, for the case with perfect foresight and no rebate,

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[17]I also compute the cumulative multiplier using the formula:

$$m_{Cumulative}^{ZLB} = \left(\frac{\sum_{t=1}^{T} \left(GDP_t^2 - GDP_t^1 \right)}{\sum_{t=1}^{T} \left(G_t^2 - G_t^1 \right)} \right) \tag{18}$$

However, the cumulative multiplier is very similar to the present value multiplier. To save space I do not report the cumulative multiplier in this paper. The additional results are available upon request.
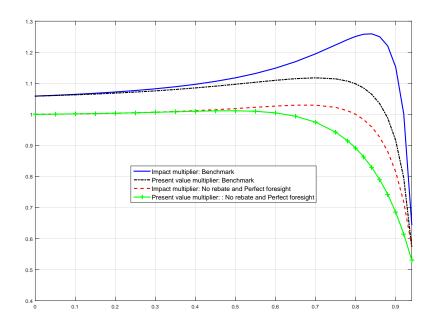
Figure 6: Government purchase multipliers at the ZLB. The ZLB binds for 10 periods on average.

both the impact multiplier and the present value multiplier are smaller than 1. In particular, the present value multiplier in this case is only around 0.8.

5.5. Generalized impulse response function (GIRF)

Due to the ZLB constraint, the policy functions, especially the one for the nominal interest rate, are highly nonlinear. Therefore, the impulse responses are both shock and state dependent, as in Koop et al. (1996). In the Results section I use the conventional impulse response function (IRF) to compute the purchase multiplier.[18] In this sub-section, I implement a robustness check to see if using GIRFs, as described in Koop et al. (1996), would change the main results. Intuitively, a GIRF for a state is the average of many IRFs starting from that state. Due to computational expensiveness resulting from Monte Carlo simulation related to GIRFs, I only compute GIRFs for the case when the government purchase persistence is 0.86, which is the benchmark value. I also plot the conventional IRFs, which I use to compute the purchase multiplier in the Results section. The results are presented in figures 7 and 8 for two different states: the steady state and the state that mimics the Great Recession. The GIRFs are computed using 9,999 draws of shocks, with each having 20 periods.

From figure 7, we are able to see that the conventional IRFs and GIRFs are very similar, especially for GDP and government purchase, as seen in panels E and F. This means that the government purchase multiplier based on the IRFs and the counterpart based on GIRFs are the same.

At the ZLB state, the IRFs and GIRFs are also the same for GDP and government

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[18]As explained in the Results section, the conventional impulse responses are computed as the difference between the responses under both preference shock and government purchase shock and the ones under only the preference shock.
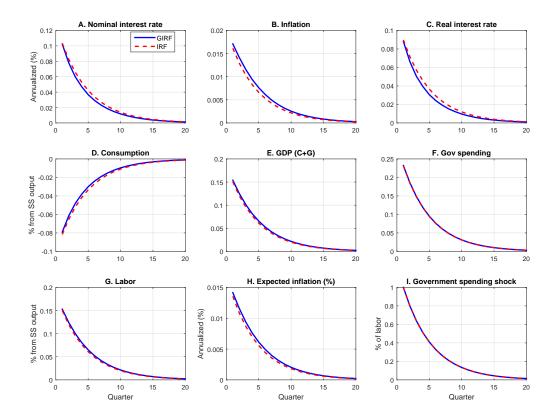
Figure 7: Conventional impulse response functions (IRFs) and Generalized impulse response function (GIRFs) at the steady state. The GIRFs are computed as the average of 9,999 IRFs starting from the steady state. See Koop et al. (1996) for more detail.
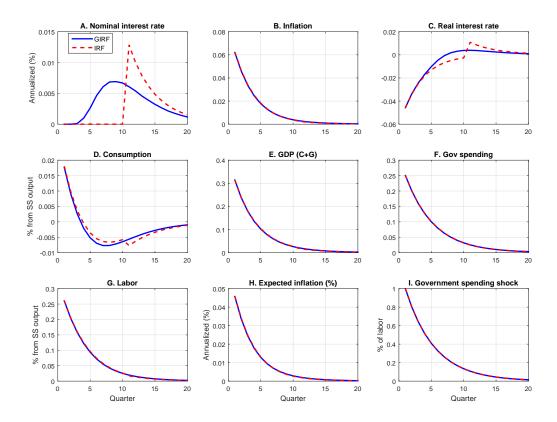
Figure 8: Conventional impulse response functions (IRFs) and Generalized impulse response function (GIRFs) at the ZLB state. The GIRFs are computed as average of 9,999 IRFs starting from the ZLB state. See Koop et al. (1996) for more detail.

purchase, as seen in panels E and F of figure 8. As a result, the government purchase multiplier is the same regardless of using IRFs or GIRFs.

However, it is interesting to note that the IRF and GIRF for nominal interest rate are very different. Again, the GIRF for nominal interest rate is the average of 9,999 IRFs starting from the same ZLB state. If I compute the GIRF using the median IRF from the set of 9,999 ones, the IRF and GIRF are very similar. The reason for the difference is that the distribution of the nominal interest is skewed to the right, so the mean is greater than the median.

6. Conclusion

This paper contributes to the literature of ZLB and the role of fiscal policy by investigating the magnitude of government purchase multiplier the ZLB. My approach is novel because it takes into account the unconditional probability of hitting the ZLB that is in line with the US data. Moreover, I compute the multiplier in a state that mimics the Great Recession. I also allow the government purchase to follow an AR(1) process and and investigates the role of government purchase persistence, not just the magnitude of purchase, on the government purchase multiplier while the economy is at the ZLB.

The main findings of the paper include: (1) The multiplier is around 1.25; (2) The greater-than-one multiplier depends on all the realistic features of the model. In the framework without occasionally binding ZLB or with transient government purchase or without rebate of the price adjustment cost, the multiplier is around 1 or less; (3) The multiplier is non-monotonic in the persistence of government purchase while the economy is at the ZLB. It becomes more pronounced when the expected ZLB duration increases.

7. Acknowledgements

Some results related to government purchase multipliers, including the non-monotonicity relationship, in this paper can be found in my previous working paper entitled *"Does Calvo Meet Rotemberg at the ZLB?"*, co-authored with Jianjun Miao. Based on numerous referees' suggestions, we removed those results out of the earlier draft. The latest version of the paper *"Does Calvo Meet Rotemberg at the ZLB?"* does not contain any results similar to the main findings of this paper.

I am grateful to Jianjun Miao for generously letting me carry some of the results

related to government purchase effectiveness from our previous paper *"Does Calvo Meet Rotemberg at the ZLB?"* to this paper. I also thank participants from the 2015 Econometric Society World Congress, the 2015 Meeting of the Society for Economic Dynamics, and the fall 2014 Midwest Macroeconomics Meeting. In addition, I gratefully acknowledge the supports from the Office of Research at Cleveland State University and the Ohio Supercomputer Center (1987).

8. References

Aruoba, B., Cuba-Borda, P., Schorfheide, F., 2018. Macroeconomic dynamics near the zlb: A tale of two countries. The Review of Economic Studies 85 (1), 87–118.

Ball, L., 2013. The case for four percent inflation. Working Paper.

Ball, L., Mazumder, S., 2011. Inflation dynamics and the great recession. IMF Working Paper.

Boneva, M. L., Braun, R. A., Waki, Y., 2016. Some unpleasant properties of loglinearized solutions when the nominal rate is zero. Journal of Monetary Economics 84, 216–232.

Center, O. S., 1987. Ohio supercomputer center. `http://osc.edu/ark:/19495/f5s1ph73`.

Christiano, L., Eichenbaum, M., Rebelo, S., 2011. When is the government spending multiplier is large? Journal of Political Economy 113, 1–45.

Coenen, G., Erceg, C. J., Freedman, C., Furceri, D., Kumhof, M., Lalonde, F., Laxton, D., Linde, J., Mourougane, A., Muir, D., Mursula, S., Resende, C. D., Roberts, J., Roeger, W., Snudden, S., Trabandt, M., int Veld, J., 2012. Effects of

fiscal stimulus in strutural models. American Economic Journal: Macroeconomics 4(1), 22–68.

Diewert, E., Fox, K., 2008. On the estimation of return to scale, technical progress and monopolistic markups. Journal of Econometrics 145, 174–193.

Dotsey, M., King, R. G., Wolman, A. L., 1999. State-dependent pricing and the general equilibrium dynamics of money and output. Quarterly Journal of Economics 114, 655–690.

Eggertsson, B. G., 2009. The simple analytics of the government spening multiplier. Federal Reserve Bank of New York Staff Report.

Eggertsson, B. G., Singh, R. S., 2016. Log-linear approximation versus an exact solution at the zlb in the new keynesian model. NBER Working Paper.

Eggertsson, G., 2011. What fiscal policy is effective at zero interest rates. 2010 NBER Macroeconomics Annual, 59 – 112.

Eggertsson, G., Krugman, P., 2012. Debt, deleveraging and the liquidity trap: A fisher - minsky - koo approach. Quarterly Journal of Economics 127(3), 1469–1513.

Fernandez-Villaverde, J., Gordon, G., Guerron-Quintana, P., Rubio-Ramirez, F. J., 2015. Nonlinear adventures at the zero lower bound. Journal of Economic Dynamics and Control 57, 182–204.

Guerrieri, V., Lorenzoni, G., 2011. Credit crises, precautionary savings and the liquidity trap. Working Paper.

Gust, C., Herbst, E. Lopez-Salido, D., Smith, M., 2017. The emperical implications of the interest-rate lower bound. American Economic Review 107(7), 1971–2006.

Gust, C., Lopez-Salido, D., Smith, M., 2012. The emperical implications of the interest-rate lower bound. Federal Reserve Board Manuscript.

Hills, T., Nakata, T., 2017. Fiscal multipliers at the zero lower bound: The role of policy inertia. Journal of Money, Credit and Banking (forthcoming).

Ireland, N. P., 1997. A small, structural, quarterly model for monetary policy evaluation. Carnegie-Rochester Conference Series on Public Policy 47, 83–108.

Judd, K. L., 1998. Numerical Methods in Economics. MIT Press.

Judd, L. K., Maliar, L., Maliar, S., 2011. A cluster-grid algorithm: Solving problems with high dimensionality. Working Paper.

Koop, G., Pesaran, M. H., Potter, S. M., 1996. Impulse response analysis in nonlinear multivariate models. Journal of Econometrics 74, 119–147.

Miao, J., Ngo, P., 2016. Does calvo meet rotemberg at the zero lower bound? Working Paper.

Miranda, M. J., Fackler, L. P., 2002. Applied Computational Economics and Finance. MIT Press.

Mishkin, F. S., 2011. Monetary policy strategy: Lessons from the crisis. NBER Working Paper.

Nakata, T., 2016. Optimal fiscal and monetary policy with occasionally binding zero lower bound. Journal of Economic Dynamics and Control 73, 220–240.

Nakata, T., 2017. Uncertainty at the zero lower bound. American Economic Journal: Macroeconomics 9(3), 186–221.

Ngo, V. P., 2014. Optimal discretionary monetary policy in a micro-founded model with a zero lower bound on nominal interest rate. Journal of Economic Dynamics and Control 45, 44–65.

Rotemberg, J., 1982. Sticky prices in the united states. Journal of Political Economy 90, 1187–211.

Wolman, A., 2005. Real implications of the zero bound on nominal interest rates. Journal of Money, Credit and Banking 37 (2), 273 – 296.

Woodford, M., 2011. Simple analytics of the government expenditure multiplier. American Economic Journal: Macroeconomics 3, 1–35.

9. Appendix

9.1. What process for government purchase shock fits the US data?

To answer this question, I first collect real GDP and real government purchase on final consumption and investment from the Federal Reserve Economic Data (FRED) website.[19] I then compute the government purchase shock as fraction of the government purchase to GDP, as described in the Model section. The fraction series is non-stationary. The null hypothesis of stationary is rejected at the 1% level based on the augmented Dicky-Fuller test with 4 lags, which is chosen by the BIC criteria. Given the model is stylized and does not deal with very slowly-moving components, such as technology growth shocks, it is reasonable to filter these very slowly-moving components out and keep cyclical components only. Figure 9 shows the filtered series based on the Hodrick-Prescott filtering method for the period 1960q1-2017q2.

It is noticeable that the the government purchase as share of GDP is counter-cyclical. It increases sharply in most recessions, and decreases during expansions. In particular, it increased about 2% during the Great Recession from 2007q4 - 2009q2. This is the largest increase since 1975.

To determine the persistence of government purchase, I use the data from 1960q1 to 2017q2 to fit an AR(1) model. The regression result is presented in Table 2.

The estimate of the government purchase persistence is 0.86 for the sample from 1960q1-2017q3. The standard deviation of the government purchase innovations is approximately $\frac{0.3}{100}$. These estimation results are robust when I use different sub-samples as shown in Table 2.

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[19]The series for real GDP and real government purchase on final consumption and investment are GDPC1 and GCEC1 respectively.
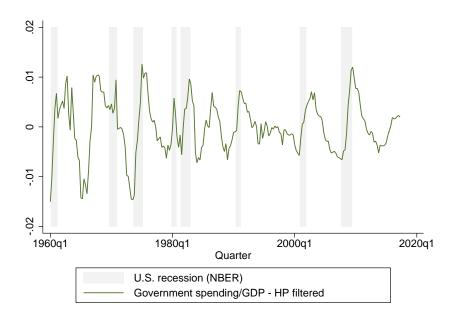
Figure 9: government purchase as fraction of GDP: 1960q1-2017q2.

Table 2: government purchase shock process

Dependent variable: government purchase/GDP	(1) 1960q1-2007q3	(2) 1980q1-2007q3	(3) 1960q1-2017q2
L.government purchase/GDP	0.85***	0.84***	0.86***
	(0.04)	(0.05)	(0.03)
Constant	0.00	-0.00	0.00
	(0.00)	(0.00)	(0.00)
Observations	190	111	229
RMSE (%)	0.28	0.22	0.27
Adjusted R^2	0.74	0.70	0.76

Note: Standard errors in parentheses.

*, **, *** denote $p\_value < 10\%, 5\%$, and 1% respectively.

9.2. Probability of hitting the ZLB

The probability of hitting ZLB plays a key role in determining the level of government purchase multiplier. Many economists, including Mishkin (2011), believe that the 2007-2009 recession with a binding ZLB is a rare disaster that occurs once every seventy years. However, other economists, i.e. Ball (2013), disagree. In this appendix I will use different methods to estimate the unconditional probability of hitting the ZLB using the actual US data.

The first method to compute unconditional probability of hitting the ZLB is:

$$\text{Pr(Policy rate=0)} = \frac{\#\text{of periods the target FFR} = 0}{\#\text{of all periods where the target FFR is available}} \quad (19)$$

Using the US data, the target FFR data span from 1982:IV-2017:II. There are 139 observations in total and 28 observations with zero (from 2008:IV-2015:III). Thus, the unconditional probability of hitting the ZLB is:

$$\text{Pr(interest rate=0)} = \frac{28}{139} = 0.2014 \text{ or } 20.14\%. \quad (20)$$

The second method is to answer the question raised in Ball (2013): what would the unconditional probability of hitting the ZLB have been, had the Fed targeted the inflation rate of 2%. To this end, I follow Ball (2013) and use the real interest rate to answer the question. Specifically, the nominal interest rate equals the real interest rate plus the expected inflation rate. Therefore, we can interpret the zero lower bound on the nominal interest rate as a lower bound of minus expected inflation for the real interest rate. If the target inflation rate is 2%, the expected inflation rate would be 2% and the lower bound on the real interest rate would be -2%. However, Ball (2013) argues that a recession is likely to push expected inflation
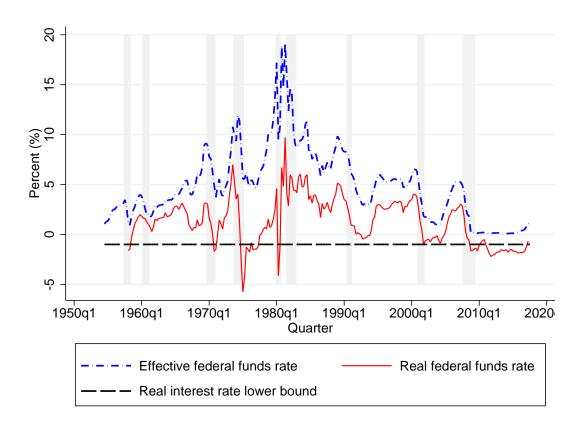
Figure 10: Real federal funds rate is the effective federal funds rate minus the inflation rate computed as a percentage change in the CPI of All Items Less Food and Energy a year ago. The shaded areas indicate the US recessions. Source: the Federal Reserve Economic Data.

down somewhat and that the history suggests that the inflation fell about 1% during the past recessions that started with $2 - 3\%$ inflation rates. Therefore, he finds that the bound on the real interest rate is -1%.

Figure 10 shows: (i) the effective federal funds rate; (ii) the real interest rate computed as the effective federal funds rate minus the inflation rate, where the inflation rate is calculated as a percentage change of the CPI of All Items Less Food and Energy from a year ago; and (iii) the lower bound of the real interest rate. The data spans from 1957:IV, when the data for the CPI of All Items Less Food and Energy was first available, to 2017:II. So, we have 239 observations in all.

From the figure, we are able to see that the real interest rate was smaller than the bound, and, as a result, the nominal interest rate might have hit the ZLB, in the five recessions: 1957:III-1958:II, 1969:IV-1970:IV, 1973:IV-1975:I, 1980:I-1980:IV, and 2007:IV-2009:II.[20] Especially, using the real interest rate, we can very well infer that the nominal interest rate reached the ZLB during the 2007-2009 recession. In addition, the nominal interest rate almost hit the ZLB in the 2001 recession.

Examining the real interest rate since 1957:IV when the CPI data was first available, I find that the ZLB was binding in 47 quarters. Given that the sample has 239 quarters, the unconditional probability of hitting the ZLB is 19.7%. When I compute the real interest rate using the CPI of All Items, the probability of hitting the ZLB is slightly smaller, around 16.1%.[21]

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[20]Ball (2013) argues that in the three out of seven recent recessions excluding the 2007-2009 recession, the nominal interest rate would have hit the ZLB if the inflation rate had been around 2% at the start of the recessions. These three recessions include the 1969-1970 recession, the 1973-1975 recession, and the 1980 recession. Hence, the probability of hitting the ZLB conditional on a recession would be around 50%, or four recessions out of eight recessions, if the Fed targeted 2% inflation rate post World World II.

[21]For a robust check, I also use the PCE index, instead of the CPI of All Items Less Food and Energy. The result is quite robust.
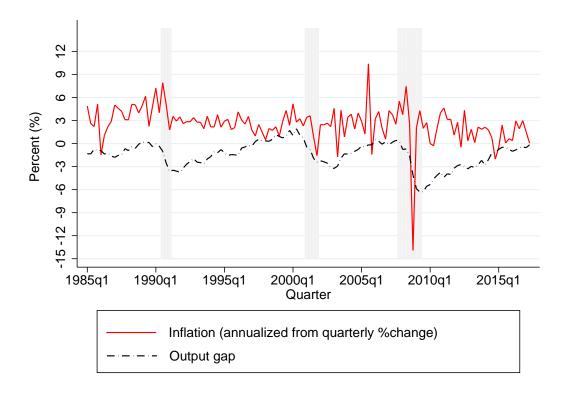
Figure 11: Output gap and inflation in the US Source: the Federal Reserve Economic Data.

In this paper I calibrate the preference shock to match the unconditional probability of hitting the ZLB 17%, which is in the lower range of [16.1%, 20.14%].

9.3. The Great Recession

It is well-known that the magnitude of government purchase multiplier depends on the state of the economy. In this subsection, I will discuss different ways to measure the adversity of the Great Recession based on that I calibrate the shocks and compute the government purchase multiplier.

Figure 11 shows the output gap and inflation series for the US. To compute the output gap I take the percentage difference between real GDP and potential real

GDP. To compute inflation, I first compute the quarterly percentage change in the CPI, then annualized it by multiplying with 4. The quarterly data on CPI (of All Items), real GDP , and potential real GDP are collected from the Federal Reserve Economic Data website hosted by the Federal Reserve Bank of St. Louis.

As seen from this figure, at the trough of the Great Recession, the output gap was as large as around -6.5% (the dash-dotted black line), and the annualized inflation rate (the solid red line) was approximately -14% or -3.5% per quarter. If I use core CPI that excludes food and energy prices, the inflation rate was much smaller. To be conservative, I target an inflation rate of only -3% per year. In conclusion, I compute the multiplier at the state that mimics the Great Recession: the expected ZLB duration is 10 quarters, output declines by around 6.5%, and the inflation rate is about -3%.