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HOW CAN THE GOVERNMENT SPENDING MULTIPLIER BE SMALL AT THE ZERO LOWER BOUND?

by Valerio Ercolani * and João Valle e Azevedo**

Abstract

Some recent empirical evidence questions the typically large size of government spending multipliers when the nominal interest rate is stuck at zero, finding output multipliers of around 1 or even lower, with an upper bound of around 1.5 in some circumstances. In this paper, we use a recent estimate of the degree of substitutability between private and government consumption in an otherwise standard New Keynesian model to show that this channel significantly reduces the size of government spending multipliers obtained when the nominal interest rate is at zero. All else being equal, the relationship of substitutability makes a government spending shock crowd out private consumption while being less inflationary, thus limiting the typically expansionary effect of the fall in the real interest rate. Subject to the nominal interest rate being constrained at zero, the model generates output multipliers ranging from 0.8 to 1.6.

JEL Classification: E32, E62.
Keywords: non-separable government consumption, substitutability, zero lower bound, fiscal multipliers.

Contents

1. Introduction 5
2. Model 9
   2.1 Households 9
   2.2 Firms 11
   2.3 Fiscal and monetary policy 11
   2.4 Market clearing 12
3. Simulations and results 12
   3.1 Parameters choice 13
   3.2 The experiment 14
   3.3 Results 15
   3.4 Robustness 19
   3.5 Large(r) multipliers under substitutability 24
4. Conclusions 25
References 26
Appendix: equilibrium conditions 30

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1 Introduction[1]

Since the end of 2008, nominal interest rates have moved towards the zero lower bound (ZLB) across major developed economies. While the Federal Reserve started to raise rates in December 2015, at the end of 2017 the Bank of Japan and the European Central Bank were not giving signs that the policy rate would soon be increased. Beyond that, Eggertson et al. (2017), among others, emphasize that such a low interest rate period occurred not only because of the negative 2007-2009 cycle; it is also related to specific secular components like aging, low fertility and sluggish productivity growth. These slow-moving forces are unlikely to soon revert, arguably making a low nominal interest rate regime (given an unchanged target for inflation) the *new normal* in the next years. Thus, the study of the effects of policy interventions when nominal interest rates are low, will surely continue to attract academics and policy makers' interest.

The ZLB state is relevant because typical interest rate monetary stimulus is, by definition, constrained, while the effects of fiscal policy can deviate substantially from what is obtained in normal times. Hence, the analysis of the effects of fiscal policy at the ZLB seems to deserve some attention, not only to validate normative statements (which we do not attempt to do) but also to try to discriminate among models (which is the preferred application of our results).

Christiano et al. (2011), henceforth CER (2011), have shown, within a calibrated New Keynesian (NK) model, that a fiscal stimulus on the spending side can be particularly effective in boosting output when the nominal interest rate is at the ZLB. To see why, suppose, as in Eggertsson and Woodford (2003), that due to some shock desired savings increase but, because of price stickiness and the ZLB, the fall in the real interest rate is not enough to re-establish the equilibrium. In this situation desired savings must decrease, which only occurs with a potentially sharp reduction in consumption and output. At this point, an increase in government spending produces, all else equal, an upward pressure on expected future inflation which translates into a lower real interest rate. This mitigates the fall in output needed to restore the equilibrium and adds to the standard upward shift of labor supply generated by the expansion in government spending. Thus, the output multipliers can be

[1]The present article has been accepted for publication at *Macroeconomic Dynamics*. Part of the work was carried out while Valerio Ercolani was working at Bank of Portugal. The authors are grateful to Pedro Amaral, Rolando Bianchi, Ettore Panetti and Pedro Teles for useful comments and suggestions. All remaining errors are of the authors. The views expressed are those of the authors and do not necessarily represent those of Bank of Italy, Bank of Portugal or the Eurosystem.

significantly larger than the ones obtained when the nominal interest rate is far from the ZLB. In one of their benchmark calibrations, CER (2011) have found an output multiplier above two, compared to a multiplier close to unity when the nominal interest rate is far above the ZLB.

Does the empirical evidence support such large government spending multipliers when nominal interest rates are close to zero? Only a few papers have attempted to answer this question, mostly because of the scarcity of ZLB episodes across countries and over time. However, to the best of our knowledge, all the recent available evidence, using state-of-the art econometric techniques, speaks in favor of output multipliers close to unity (or lower) even when interests rates are near zero. Ramey (2011) provides this evidence for the US while Crafts and Mills (2013) do so for the UK. Bruckner and Taludhar (2014) find the same type of result using regional government spending data in Japan. As for the upper bound of these effects, one should mention Ramey and Zubairy (2018) and Miyamoto et al. (forthcoming). As for Ramey and Zubairy (2018), they find, for the US and Canada, multipliers as high as 1.5 in a few specifications when, for instance, the World War II period is not included in the sample. Still, in the bulk of the exercises performed at the ZLB, the authors find multipliers around unity, or lower. Miyamoto et al. (forthcoming) find impact multipliers of 1.5 at the ZLB, using data on government spending forecasts in Japan.[2]

In this paper, we focus on one specific mechanism that helps reduce the gap between the government spending multipliers obtained in CER (2011) and those resulting from the recent empirical analyses: the degree of substitutability between private and government consumption. Most macro models, including CER (2011), assume that government consumption is either pure waste or enters separably in the household's utility function. However, this assumption has been questioned by several works. Among others, Aschauer (1985) and Ercolani and Valle e Azevedo (2014) –EVA (2014) henceforth– find substitutability between private and government consumption in the US, as in the model suggested by Barro (1981). Ahmed (1986) finds the same relationship for the UK. Evans and Karras (1998) find, for many developed and industrialized countries, substitutability between private and (non-military) government consumption.[3] Several examples are compatible with the estimates of substitutability,

[2]A much higher level of heterogeneity characterizes the results for the size of government spending multipliers during periods of slack or recessions. For example, Auerbach and Gorodnichenko (2012 and 2013) find larger multipliers during recessions compared to normal times, whereas Owyang et al. (2013) do not.

[3]We agree that the debate on the degree of substitutability is still open in the literature. For example, Karras (1994), analyzing thirty countries, finds that the two types of goods are best described as complements (but often unrelated), while Bouakez and Rebei (2007) find a relationship of complementarity for the US. EVA (2014) show that this latter result is driven by the no inclusion of government spending data in the estimation and by fixing relevant parameters in

e.g., rises in the number of physicians in the public health sector may reduce the need for privately provided medical examinations and treatments, or, boosts to public education services can reduce the need for private schools and tutors.

Substitutability has the potential to tame the size of the output multiplier, especially when nominal interest rates are stuck at zero, because the government spending shock becomes less inflationary. The reasoning goes as follows. An increase in government consumption makes private consumption less enjoyable, or, the marginal utility of private consumption decreases. This leads agents to partially substitute private consumption with newly available government consumption. Aggregate demand is lower with respect to the one in the 'separable' world, reducing competition among firms for inputs and, hence, input prices.[4] As a consequence, marginal costs and inflation are lower. This mitigates the fall in the real interest rate, which is the key driving force for the expansion of aggregate demand during the ZLB episode. Eventually, output is lower in the 'non-separable' world because both demand and supply forces operate. On the one hand, the lower aggregate demand translates into the supply side if nominal rigidities are present. On the other hand, agents supply less labor in order to finance the lower level of consumption, negatively affecting labor's contribution to production.

To perform our analysis, we use an otherwise standard NK model –solved non-linearly– and allow government consumption to affect households' marginal utility of consumption. The degree of substitutability is set using a recent estimate by EVA (2014). Conditional on the nominal interest rate at the ZLB, we show that the channel under scrutiny (substitutability) is able to significantly reduce the size of the government spending multiplier obtained in CER (2011). More precisely, the impact output multiplier generated by the 'non-separable' model is roughly half the one generated by the 'separable' model, ranging between 0.8 and 1. This finding is robust to different financing/taxation schemes; it obtains in versions of the model where Ricardian equivalence holds as well as in versions characterized by a debt-stabilizing income tax rule. In some specifications, we are able to obtain somewhat bigger multipliers (up to 1.6 after some quarters), which is in line with the abovementioned upper bound estimate of Ramey and Zubairy (2018).

Other papers have investigated on those channels that potentially dampen the size of government

the utility function. Finally, Feve et al. (2013) estimate a relationship of complementarity for the US. Below we try to reconcile this latter result with the estimation results in EVA (2014), see footnote 5.

[4]From now onwards, the notion of 'separable' economy indicates the case in which private and government consumption are unrelated through preferences. Instead, the 'non-separable' label refers to the the case where the two goods are substitute goods.

spending multipliers when interest rates are at zero. The analysis closest to ours is due to Albertini et al. (2014), who obtain low multipliers if the composition of the fiscal stimulus, financed with only lump-sum taxes, is tilted towards (perfectly) substitutable government consumption and productive public investment. We contribute to this analysis in several ways. First, we use estimated values of the degree of substitutability between private and government consumption instead of imposing perfect substitutability. Second, and importantly, we explain carefully how the channel of utility-enhancing government consumption interacts with the ZLB state, while showing the reactions of all the model's variables to our fiscal shock. Finally, our model allows for the analysis of different financing schemes, including with distortionary taxes in the presence of a fiscal rule. Regarding other related works, Mertens and Ravn (2014) show that output multipliers can be below unity if the liquidity trap is caused by a self-fulfilling state of low confidence rather than preference shocks. Swanson and Williams (2014) focus on the term structure of interest rates, suggesting that 1- and 2-year Treasury yields were unconstrained throughout 2008 to 2010, implying that fiscal multipliers retained normal values during this period. Drautzburg and Uhlig (2015) estimate an extended version of the Smets-Wouters (2007) New Keynesian model, focusing on both myopic consumers and distortionary taxation at the ZLB. Among other findings, they show that the more 'aggressive' is the debt-stabilizing fiscal rule, the lower is the government spending multiplier. We contribute to the last three papers by analyzing a competing, but not mutually exclusive, channel based on the relationship in preferences between private and government consumption.

More generally, our analysis can be viewed as a contribution to the literature that studies the stabilizing effects of government spending when the nominal interest rate is at the ZLB. Samples of this literature are Eggertson (2010 and 2011), Cogan et al. (2010), Woodford (2011), Aruoba et al. (forthcoming) and Erceg and Lindé (2014).

Finally, our results can inform the debate on the welfare effects of a government spending expansion during a ZLB period. Interestingly, Bilbiie, Monacelli and Perotti (2017) show that these effects depend in important ways on how government spending influences agents' preferences.

The structure of the paper is as follows. Section 2 briefly describes the model. Section 3 presents the results. Section 4 concludes.

2 Model

We use an otherwise standard NK set-up similar to a vast class of models, e.g., Schmitt-Grohé and Uribe (2006), henceforth SGU (2006), and Smets and Wouters (2007). We deviate from these models in that we allow government consumption to affect the household's marginal utility of consumption. We maintain various empirically plausible elements of these previous models which have proven useful in providing a good fit to the data. In what follows, we simplify the exposition of the micro-foundations of the model, as they are now standard.

2.1 Households

The economy is populated by a large representative household composed of a continuum of members indexed by $h \in [0,1]$. The household derives utility from effective consumption, $\tilde{C}_t$, and disutility from working L_t, where $L_t = \left[\int_0^1 L_t(h)^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dh\right]^{\frac{\varepsilon_w}{\varepsilon_w - 1}}$. $L_t(h)$ is the quantity of labor of type h supplied and ε_w is the elasticity of substitution across varieties. L_t is supplied by labor packers to intermediate goods firms in a competitive market at cost $W_t = \left[\int_0^1 W_t(h)^{1-\varepsilon_w} dh\right]^{\frac{1}{1-\varepsilon_w}}$, where $W_t(h)$ is the price of each labor variety. Effective consumption is assumed to be an Armington aggregator of private consumption, C_t, and government consumption, G_t:

$$\tilde{C}_t = \left[\phi \left(C_t\right)^{\frac{\upsilon-1}{\upsilon}} + (1-\phi)\, G_t^{\frac{\upsilon-1}{\upsilon}}\right]^{\frac{\upsilon}{\upsilon-1}}, \tag{1}$$

where $\phi \in [0,1]$, and $\upsilon \in (0;\infty)$ is the elasticity of substitution between C_t and G_t. Conditional on $\phi < 1$, large values of υ make C_t and G_t substitutes. If $\phi = 1$ then $\tilde{C}_t = C_t$ and the standard hypothesis of separability emerges. In turn, C_t is a bundle of goods $C_t(j)$, with $j \in [0,1]$, assembled by a final goods firm operating in competitive markets and given by $C_t = \left[\int_0^1 C_t(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}$, where ε is the elasticity of substitution across varieties of goods. This bundle costs $P_t = \left[\int_0^1 P_t(j)^{1-\varepsilon} dj\right]^{\frac{1}{1-\varepsilon}}$, where $P_t(j)$ is the price of each variety. The lifetime expected utility of the representative household is given by:

$$E_0 \left\{ \sum_{t=0}^{\infty} e^{\lambda_t} \beta^t \left[\frac{\left(\tilde{C}_t - \theta \tilde{C}_{t-1}^A\right)^{1-\sigma_c}}{1-\sigma_c} - \chi \frac{L_t^{1+\sigma_L}}{1+\sigma_L} \right] \right\}, \tag{2}$$

where σ_c denotes the degree of relative risk aversion, σ_L is the inverse of the Frisch elasticity of labor supply, $\theta \in (0;1)$ measures the degree of habit formation in (aggregate) effective consumption $\tilde{C}_t^A$, $\beta \in (0,1)$ is the subjective discount factor, and χ is a preference parameter. λ_t represents a discount factor shock, assumed to follow a first-order autoregressive process with an i.i.d. error term: $\lambda_t = \rho_\lambda \lambda_{t-1} + \eta_t^\lambda$. As in CER (2011), this shock is crucial in bringing the economy to the ZLB. The representative household faces the following budget constraint in real terms:

$$(1+\tau^c)C_t + I_t + B_t = \frac{R_{t-1}}{\pi_t} B_{t-1} + (1-\tau_t)\frac{1}{P_t} W_t L_t + (1-\tau_t)\left[r_t^k u_t - a(u_t)\right]\bar{K}_t + D_t - T_t, \quad (3)$$

where R_t is the gross nominal interest rate on governments bonds, B_t, $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate (hence, the gross ex-post real risk-free rate is given by $R_t^f = \frac{R_{t-1}}{\pi_t}$), $W_t L_t$ is labor income, $\bar{K}_t$ is the capital stock, D_t are the dividends paid by household-owned firms, and T_t are lump-sum taxes. τ^c and τ_t are tax rates on consumption and income, respectively. Following SGU (2006), the cost of using capital at intensity u_t is given by $a(u_t) = \gamma_1 (u_t - 1) + \frac{\gamma_2}{2}(u_t - 1)^2$. The effective capital, $K_t = u_t \bar{K}_t$, is rented to firms in a competitive market at cost r_t^k (return to capital). $\bar{K}_t$ evolves according to:

$$\bar{K}_t = (1-\delta_k)\bar{K}_{t-1} + I_t\left[1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right], \quad (4)$$

where δ_k is the depreciation rate and κ governs the cost of changing the current level of investment I_t, relative to I_{t-1}.

The representative household maximizes its lifetime expected utility by choosing C_t, B_t, $\bar{K}_t$, I_t, and u_t subject to (3) and (4). Each of the members of the household supplies $L_t(h)$ units of labor while re-optimizing the (nominal) wage, $W_t(h)$, with probability $1-\xi_w$ in each period t, where $\xi_w \in [0,1]$. Members re-optimizing their wage maximize their expected utility in all states of nature in which they are unable to re-optimize in the future, subject to (3) and the demand for labor services, $L_{t+s}(h) = \left(\frac{W_t(h)}{W_{t+s}}\right)^{-\varepsilon_w} L_{t+s}$, generated by the labor packers. Households who do not re-optimize at time t set their wages according to the rule $W_t(h) = W_{t-1}(h)$.

2.2 Firms

There is a continuum of household-owned monopolistic firms, indexed by $j \in [0,1]$, each of which produces differentiated goods, $Y_t(j)$, using the following technology:

$$Y_t(j) = \max(K_t(j)^\alpha L(j)^{1-\alpha} - \Phi, 0), \tag{5}$$

where $Y_t(j)$ is the output of good j, α is the share of capital, and Φ represents a fixed cost of production. Capital, $K_t(j)$, and labor, $L(j)$, are obtained in competitive markets. At each period t, a share $1-\xi_p$ of firms, where $\xi_p \in [0,1]$, resets its price, $P_t(j)$. Firms resetting $P_t(j)$ in period t maximize the expected present discounted value of dividends in the states of nature in which they are unable to re-optimize, i.e., they solve:

$$\max_{P_t(j)} E_t \left\{ \sum_{s=0}^{\infty} \xi_p^s \beta_{t,t+s} Y_{t+s}(j) \left[P_t(j) - MC_{t+s}\right] \right\}, \tag{6}$$

subject to the demand $Y_{t+s}(j) = \left(\frac{P_t(j)}{P_{t+s}}\right)^{-\varepsilon} Y_{t+s}$ generated by the final goods firm, where $Y_{t+s} = \left[\int_0^1 Y_{t+s}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}$. $\beta_{t,t+s}$ is the stochastic discount factor of the households and $MC_t = \frac{\left(r_t^k\right)^\alpha W_t^{1-\alpha}}{\alpha^\alpha (1-\alpha)^{1-\alpha}}$ is the marginal cost. Those firms which cannot re-optimize will instead set their prices according to the rule $P_t(j) = P_{t-1}(j)$.

2.3 Fiscal and Monetary Policy

The government buys G units of final goods each period. Its budget constraint is:

$$G_t + \frac{R_{t-1}}{\pi_t} B_{t-1} = B_t + \tau^c C_t + \tau_t \frac{W_t}{P_t} L_t + \tau_t \left[r_t^k u_t - a\left(u_t\right)\right] K_t + T_t, \tag{7}$$

We assume a first-order autoregressive process for G_t with an i.i.d error term, i.e.:

$$G_t = (1-\rho_G) G_{ss} + \rho_G G_{t-1} + \eta_t^G$$

where G_{ss} is the steady-state level for G and η_t^G is a white noise error term. Following Traum and Yang (2011), we assume the income tax rate follows:

$$\tau_t = (1-\rho)\tau_{ss} + \rho\tau_{t-1} + (1-\rho)\gamma\left(\frac{B_{t-1}}{Y_{t-1}} - b_{ss}\right), \tag{8}$$

where τ_{ss} and b_{ss} are the steady state values of τ_t and $\frac{B_t}{Y_t}$, respectively. Importantly, γ controls the speed of adjustment of the debt to output ratio towards its steady-state. Whenever $\gamma \neq 0$, we assume that lump-sum taxes, T_t, remain fixed at their steady state value, T_{ss}, compatible with G_{ss}, τ^c, τ_{ss} and b_{ss} (i.e., only the income tax is used to stabilize the debt-ratio). We also analyze the Ricardian version of the model, i.e., we set $\gamma = \rho = 0$ and assume the government balances the budget.

Finally, the monetary authority sets the nominal interest rate according to a Taylor rule:

$$R_t = \max(Z_t, 1), \quad \text{where} \quad Z_t = (Z_{t-1})^{\alpha_z}(\pi_t - 1)^{\phi_\pi(1-\alpha_z)} * \left(\frac{Y_t}{Y_{t-1}} - 1\right)^{\phi_y(1-\alpha_z)}. \tag{9}$$

2.4 Market clearing

In equilibrium, all markets clear and the resource constraint, $Y_t = C_t + I_t + G_t + a(u_t)K_t$, completes the model.

All the equilibrium conditions required to solve the model and perform simulations can be found in the appendix.

3 Simulations and Results

In this section, we first parameterize our model by borrowing several values from existing literature that focuses on the US economy. Then, we perform some experiments, characterized by an increase in government spending conditional on the nominal interest rate having reached the ZLB. We evaluate two alternative financing schemes: one characterized by a debt-stabilizing income tax rule (our baseline model) and another one where only lump-sum taxes adjust. We also analyze how a different degree of fiscal adjustment influences the size of the multipliers. Further, we provide a comprehensive robustness analysis aimed at understanding how deviations from our benchmark experiment (both in terms of parameterization and in the size of shocks) affect our results. Finally, we pay special attention to realistic deviations from the benchmark that are able to generate larger multipliers.

3.1 Parameters Choice

The time unit is the quarter. Concerning the parameters of greatest interest, i.e., the ones influencing the relationship in preferences between private and government consumption, we proceed as follows. Whenever we consider substitutability between private and government consumption we set ϕ and $log(v)$ equal to 0.66 and 7.9, respectively, which are the (mode) values estimated in EVA (2014).[5] The high value of v implies that the aggregator in (1) becomes almost linear ($\tilde{C}_t \approx \phi C_t + (1-\phi)\, G_t$), as in the specification estimated by Aschauer (1985) or Ahmed (1986). On the contrary, imposing separability between C and G amounts to setting $\phi = 1$.

Regarding the parameters governing fiscal and monetary policy, we proceed as follows. Concerning the fiscal and the monetary policy rules, we follow Traum and Yang (2011). To what concerns the first one, we set $\rho = 0.92$ and $\gamma = 0.094$.[6] For the monetary policy rule, we set $\alpha_z = 0.86$, $\phi_y = 0.12$ and $\phi_\pi = 2.0$. Further, τ_{ss} is set to 0.2 which is roughly the mean of the tax rates on wages and capital as calibrated by Leeper et al. (2010), while τ^c is set to 0.028 following the same source. Finally, G_{ss} is set such that the government consumption-to-output ratio in steady state is the average of the ratio in the post 1984 period, i.e., roughly 0.16. The persistence parameter of the government spending shock, ρ_G, is set to 0.85. The steady-state value of debt, b_{ss}, is set such that the annualized government debt-to-output ratio is roughly that of the end of 2008, 0.65, when the nominal interest rate reached the ZLB.

The following parameters are set around values that are common in the literature, e.g., see CER (2011) or SGU (2006). Regarding the preference parameters, we set $\sigma_c = 2$, $\sigma_L = 1$, $\theta = 0.7$ and

[5] It is important to notice that Feve et al. (2013) point out that not allowing for any form of countercyclical government spending leads to an overestimation of the elasticity of substitution between private and government consumption. We also acknowledge the potential caveat related to the fact that EVA (2014) employ an RBC setting while here we use a New Keyenesian framework. In order to address these issues, we have moved along two parallel routes. On the one hand, we have estimated the model of EVA (2014) allowing for countercyclical government spending. Detailed estimation results are available in Ercolani and Valle e Azevedo (2017). Very briefly, the main results are as follows: under general forms of countercyclical government spending rules within the original RBC setting (and conditional on the set of observables used there), the estimation still points towards a relationship of strong substitutability between private and government consumption. This result remains valid even if we estimate the model within a New Keynesian (nominal rigidities) framework. Next, we should mention that using hours instead of output in the set of observables and employing a linear aggregator of private and government consumption (like Feve et al. 2013) overturns this result: in this case the estimation points towards complementarity. On the other hand, we have assessed the sensitivity of our results to (much lower) values of v deemed "credible" in EVA (2014), see Section 3.4 for details.

[6] These two parameters imply 10 years for the debt ratio to reach its steady state after the fiscal shock occurs.

$\beta = 0.999$. Further, χ is set such that, in steady state, L_t is 0.31. Regarding the nominal stickiness, we set $\xi_w = 0.72$ and $\xi_p = 0.75$. Concerning the elasticities of substitution for goods and labor, we set $\varepsilon_w = \varepsilon = 6$. Further, we set Φ such that the profits-to-output ratio is 10% in the steady state. Concerning the parameters affecting the formation of capital, we set $\delta_k = 0.025$, $\kappa = 2.48$ and $\gamma_2 = 0.0685$. Finally, notice that the persistence parameter of the discount factor process, ρ_λ, is set to the benchmark value of 0.5.

3.2 The Experiment

In order to make the nominal interest attain the ZLB, we follow a strategy similar to CER (2011) and assume that the economy is in its steady state level in quarter 0. Then, we shock λ_t at quarter 1, such that agents' desire to save increases. We tune the shock such that, across all our simulations, the nominal interest rate hits the ZLB on impact and remains there for roughly 6 quarters.[7] In the model with separable government consumption and fiscal rule, this generates a sizeable fall in aggregate demand, output and partly on prices, e.g., output and consumption fall by roughly 4.5% and 5%, respectively, absent any other shock. At quarter 1, we also generate an increase in government consumption of 1% of steady state output.[8] Then, we assume that G follows a deterministic path, i.e., the autoregressive process described above without any uncertainty.[9] We then calculate the (counterfactual) dynamic government-spending multipliers t quarters after the increase in G following:

$$M_t^{ZLB} = \frac{\sum_{k=0}^{t} (R_{ss}^f)^{-k} \left[Y_k^{G,\lambda} - Y_k^{\lambda} \right]}{\sum_{k=0}^{t} (R_{ss}^f)^{-k} \left[G_k - G_{ss} \right]}, \tag{10}$$

where R_{ss}^f is the steady state (gross) real interest rate, $Y^{G,\lambda}$ is the output reaction to both the government and discount factor shocks whilst Y^{λ} is the output reaction to the discount factor shock

[7] In several of the experiments it would be feasible to increase the number of quarters at the ZLB (say, to 12). However, numerical complications arise in many of them. Hence, we decided to consider a lower number of periods at the ZLB for our benchmark simulation, while recognizing that this lowers, in general, the size of the multipliers. All in all, in our setting, the effect of substitutability on the size of the multipliers does not change significantly with the length of the ZLB episode; see also the robustness analysis in Section 3.4.

[8] This simulated increase in G is close to the maximum increase actually reached by government purchases as a result of the implementation of the *American Recovery and Reinvestment Act.*

[9] Government spending follows a deterministic path described by $G_t = (1-\rho_G)G_{ss} + \rho_G G_{t-1} + \eta_t^G$, with η_t^G representing the actual size of the spending shock in the moment of the shock (1% of steady-state output) and zero after that period.

alone.[10]

We compute the (non-linear) perfect foresight solution of the model using the algorithm in Juillard (1996).

3.3 Results

Figure 1 shows both dynamic multipliers and impulse responses generated by the above described government spending shock, within the model described in Section 2 (the baseline model). These reactions are 'counterfactual' in the sense described above (i.e., they are the difference between the responses to both shocks, preference and spending, and the responses to only the preference shock). The solid lines represent the reactions conditional on imposing substitutability between C and G and are labeled as *Substitutability.* The dashed lines represent the reactions conditional on imposing separability between C and G and are labeled as *Separability.*

Irrespective of both the relationship in preferences between G and C and the nominal interest rate being stuck at zero, the increase in government spending generates the well-known "negative wealth effect". Agents' permanent income is reduced because the present value of taxes increases. As a consequence, agents optimally respond by consuming less and working more.

When the nominal interest rate is at the ZLB, the increase in G generates a negative real risk-free rate because of the (positive) impact on inflation. This induces agents to consume more and save less, ceteris paribus. However, and crucially, the real risk-free rate falls less in the non-separable economy and thus, in this economy, household are induced to consume less relative to the separable case. The behavior of the real risk-free rate is determined by inflation, which increases less in the non-separable economy.[11] This happens because of the behavior of the marginal cost. Indeed, labor reacts less in the non-separable economy both because agents needs to supply less labor in order to finance a lower level of consumption and firms hire less labor to satisfy the lower aggregate demand (i.e., both consumption and investment are lower in the non-separable economy). These dynamics for labor generates a smaller reaction of the marginal product of capital, hence, of the return to capital (r_t^k), in the non-separable economy. The same happens for the wage rate. As a consequence, marginal costs are lower in the

[10] The notion of 'dynamic' multiplier is taken from Uhlig (2010), and the one of 'counterfactual' multiplier from CER (2011).

[11] Notice that we report the response of gross inflation. Hence, the difference in the reaction of net inflation between the two worlds is around 0.5 percentage points.

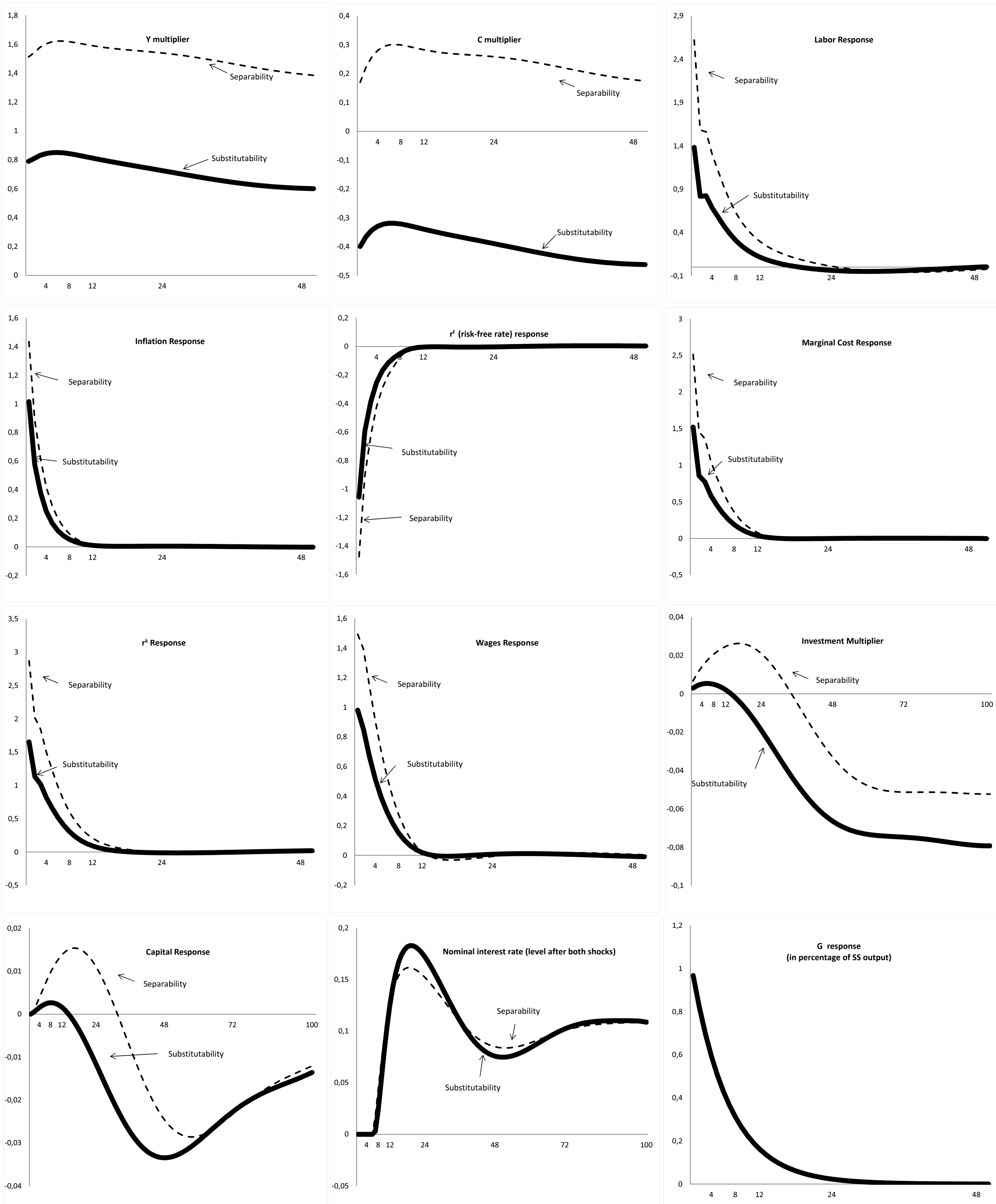

Figure 1

Multipliers/Responses in the Baseline Model. The lines are computed in the version of the model where the fiscal rule is at work. Solid lines are obtained by imposing substitutability between C and G. Dashed lines are obtained by imposing separability between C and G. Counterfactual multipliers or responses are reported, i.e., the difference between the reactions generated by the government consumption and the discount factor shocks and those generated by the discount factor shock alone (refer to equation (10) for the multipliers). The y-axis for the 'Responses' is measured in percentage deviation, except in the cases of nominal interest rate (which refers to the level after both shocks) and G (measured in percentage of steady-state output). The x-axis is in quarters.

non-separable world. Obviously, the behavior of consumption is also directly affected by the degree of substitutability, i.e., private consumption falls because it is partly substituted by the newly available government consumption.[12]

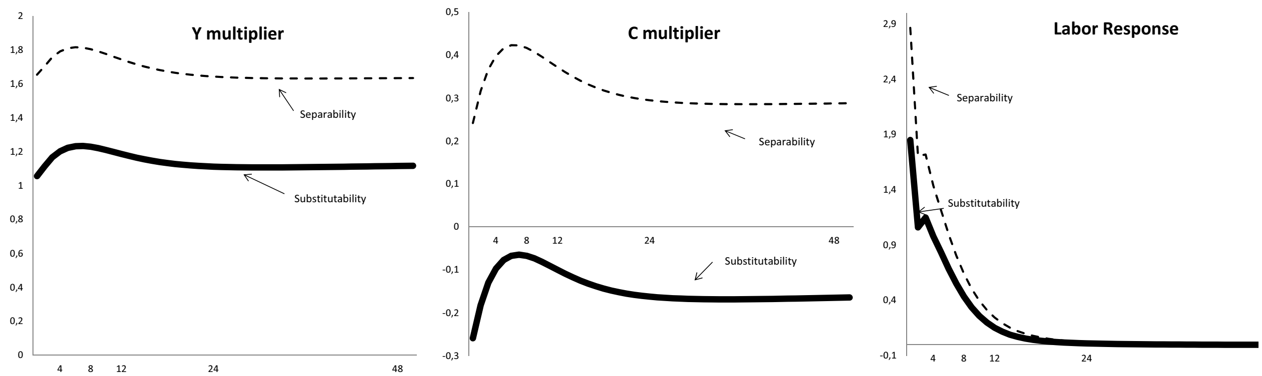

Figure 2

Multipliers/Responses in the Ricardian Model. The lines are computed in the version of the model where only lump-sum taxes adjust to balance the budget, i.e., the income tax rate is fixed at its steady state level. Solid lines are obtained by imposing substitutability between C and G. Dashed lines are obtained by imposing separability between C and G. Counterfactual multipliers or responses are reported, i.e., the difference between the reactions generated by the government consumption and the discount factor shocks and those generated by the discount factor shock alone (refer to equation (10) for the multipliers). The y-axis of the panel for 'Labor Response' is measured in percentage deviation. The x-axis is in quarters.

Eventually, output is depressed in the non-separable economy through supply and demand forces. On the one hand, the lower aggregate demand translates into the supply side because of the presence of nominal rigidities. On the other hand, the lower level of inputs (both labor and capital) results in lower output. Quantitatively, the impact output multiplier is around 0.8 and 1.5 in the non-separable and in the separable economy, respectively.

Figure 2 shows the reactions of output, consumption and labor in the Ricardian version of the model, i.e., where the increase in G is financed only by lump-sum taxes. Two things are worth noting. First, although the magnitude of these reactions is different vis-à-vis the economy with a fiscal rule at work, the gap in the output multipliers generated by the substitutability mechanism does not change significantly, i.e., it is roughly 0.75 and 0.6 in Figures 1 and 2, respectively.[13] This confirms that the channel under scrutiny (substitutability) plays a crucial role in determining the size of the output multipliers, irrespective of the way the stimulus is financed. Second, the output multipliers in the

[12]In the non-separable economy, we obtain a negative consumption multiplier for every time horizon. Notice that other channels, not considered in the present analysis, could have dampened (or reverted) this negative reaction. For example, the presence of liquidity constrained individuals as in Gali' et al. (2007), could contribute to generate a positive response of private consumption despite the relationship of substitutability between private and government consumption.

[13]This result is largely confirmed even when we vary the parameters of the fiscal rules (see Table 4 in Section 3.4). Notice that we measure the part of the multipliers due to the substitutability channel when the multipliers peaks. However, such a measure is quite homogenous over the whole reported horizon.

Ricardian world are bigger than the ones generated in our benchmark economy with a fiscal rule. This result is in line with the recent conclusions of Drautzburg and Uhlig (2015), who find –within a model economy similar to ours– that while at the ZLB the more 'aggressive' is the fiscal rule, the lower are the output multipliers. In particular, higher distortionary taxes tend to persist after the ZLB period, and this can create a negative effect on output through a disincentive on labor supply, i.e., the typical neoclassical effect.

Notice, however, that when the ZLB restriction binds, multipliers under Ricardian equivalence can be smaller than multipliers under a fiscal rule. Figure 3 shows four sets of dynamic multipliers under the specification with substitutability: one generated within the Ricardian version of the model and the others conditional on three different types of debt adjustment: a weak, an intermediate and a strong adjustment.[14] The output and consumption multipliers, generated conditionally on the weak fiscal adjustment, are bigger than the ones of the Ricardian economy. As realized by Eggertson (2010), (2011) and CER (2011), an increase in the labor tax leads to a rise in the marginal cost that positively affects inflation. At the ZLB, this depresses the real interest rate which fosters an economic expansion. To sum up: at the ZLB, distortionary taxes generate contrasting output effects because of the trade-off between the typical 'neoclassical effect' and the one generated by the ZLB state. Obviously, the stronger is the fiscal adjustment, the more the first effect prevails over the second one. Our model is flexible enough to well capture such trade-off.[15]

[14]The strong adjustment amounts to set the parameter γ in the fiscal rule to 0.164, implying 5 years for the debt to reach the steady state after the shock occurs. These two numbers become 0.094 and 10, respectively, in the case of the intermediate adjustment. Notice that this case represents our benchmark calibration. Finally, the numbers relative to the case of the weak adjustment are 0.024 and 25, respectively.

[15]One could argue that a very weak fiscal adjustment (say, $\gamma = 0.024$) is a more reasonable characterization of the behaviour of fiscal policy over the last years in the context of a sharp increase in public debt, i.e., the Traum and Yang (2011) estimate of $\gamma = 0.094$ may be too high to correctly assess the effects of fiscal policy after 2008.

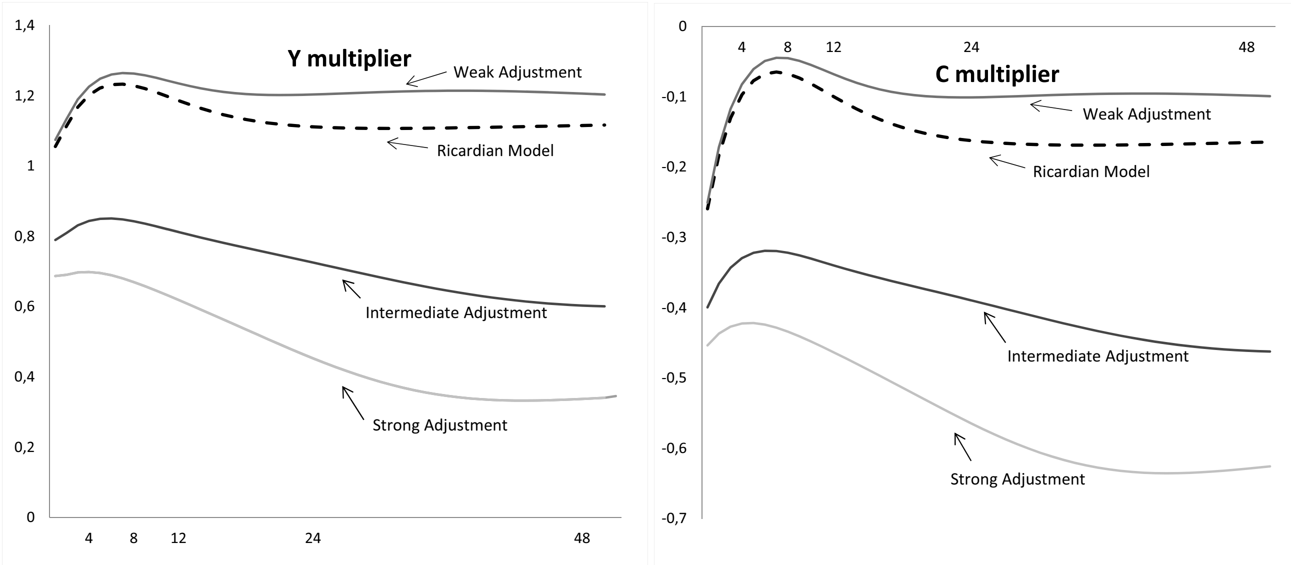

Figure 3

Multipliers under different Fiscal Adjustments. The solid lines are computed in the version of the model where the fiscal rule is at work, while the dashed lines are generated within the Ricardian economy. The multipliers are calculated imposing substitutability between C and G. These are counterfactual multipliers, i.e., the difference between the multiplier generated by the government consumption and the discount factor shocks and that generated by the discount factor shock alone (refer to equation (10)). Intermediate adjustment refers to our standard parameterization of the fiscal rule ($\gamma = 0.094$, or about 10 years to stabilize the debt ratio). Weak adjustment sets $\gamma = 0.024$ (or roughly 25 years to stabilize debt) and strong adjustment sets $\gamma = 0.164$ (or about 10 years to stabilize the debt ratio). The x-axis is in quarters.

3.4 Robustness

Several parameters or features of our experiment may have a relevant quantitative impact on the size of the multipliers. Here we assess the robustness of our results to reasonable deviations from our benchmark experiment, focusing on multipliers obtained at the zero lower bound, i.e., after the preference shock hits our model economy. We consider a bigger discount factor shock (which results in a potentially longer ZLB period and a deeper recession on impact), alternative values of the inverse of Frisch elasticity of labor supply (σ_L) and of the degree of substitutability between private and public consumption ($log(v)$). We further pay special attention to the size and persistence of the government consumption shock and the way this spending is financed, considering different speeds of adjustment of government debt towards its steady state level (measured by γ) and different degrees of persistence of the income tax rate (measured by ρ).

From Table 1 we observe that the larger is the discount factor shock the bigger is the multiplier, in line with what CER (2011) and many other papers document. This occurs under separability, with the dynamic output multiplier reaching 2.26 after 32 quarters when the largest shock is considered, but also under substitutability, in which case the dynamic multiplier does not go above 1.25. Still, under a larger preference shock (implying in general a longer ZLB period), the substitutability mechanism explains a significant part of the multipliers.

Table 1

Dynamic Output Multipliers at the ZLB - Varying size of Discount factor shock

Quarters	1	2	4	8	12	24	32	48	100
β shock 0.11									
Separability	1.51	1.54	1.60	1.62	1.59	1.54	1.49	1.39	1.38
Substitutability	0.79	0.81	0.84	0.84	0.81	0.73	0.67	0.60	0.60
β shock 0.15									
Separability	1.77	1.81	1.90	1.95	1.95	2.01	2.00	1.87	1.87
Substitutability	0.97	0.99	1.04	1.05	1.04	1.03	1.00	0.91	0.92
β shock 0.17									
Separability	1.91	1.94	2.04	2.10	2.12	2.25	2.26	2.11	2.12
Substitutability	1.10	1.11	1.15	1.18	1.19	1.25	1.24	1.12	1.13

Note: We use the benchmark parameter values and shocks. Under separability $\phi = 1$ and under substitutability $\phi = 0.66$ and $log(v) = 7.9$. The benchmark discount factor shock is set to 0.11 such that the economy stays at the ZLB for 6 quarters. A bigger discount factor shock implies a potentially longer ZLB period (the maximum numerically feasible discount factor shock implied a ZLB period of 9 quarters) and a deeper recession

Next, we observe (see Table 2) that the lower is the Frisch elasticity (i.e., the higher is the inverse of the Frisch elasticity σ_L), the higher is the output multiplier. We should refer that in normal times (i.e., away from the ZLB) the comparative statics in our model and elsewhere go the other way: the lower the Frisch elasticity is, the lower the multipliers are, as the response of labor caused by the wealth effect associated with the expansion of government spending decreases with such elasticity. Quantitatively, the differences in the multipliers are somewhat relevant, with low Frisch elasticities (those favored by microdata) delivering multipliers around two when separability is imposed whereas a Frisch elasticity of 2.0 ($\sigma_L = 0.5$) or 4.0 ($\sigma_L = 0.25$) results in only somewhat lower multipliers vis-à-vis the benchmark value ($\sigma_L = 1.0$), both under separability and under substitutability.

Regarding v, the elasticity of substitution between government and public consumption, we notice (see Table 3) that within the substitutability region, the differences in the associated multipliers are not substantial.[16] Also, and counterintuitively, a lower degree of substitutability is associated with a lower multiplier. We stress again that the differences are not pronounced. We have verified that this also occurs in normal times and is a result of the preferences we employ, which include habit formation and non-log utility. Using log utility and not considering habit formation ($\theta = 0$), the more conventional comparative statics obtain, along with even less pronounced differences across degrees of substitutability. What is always clear is that the multipliers are significantly lower in

[16]This region includes also $log(v) = 0.65$, which is the lower bound of the 95% 'credibility' interval in EVA (2014).

Table 2

Dynamic Output Multipliers at the ZLB - Varying Frisch Elasticity

Quarters	1	2	4	8	12	24	25	48	100
$\sigma_L = 0.25$									
Separability	1.28	1.28	1.30	1.30	1.27	1.17	1.09	1.00	1.01
Substitutability	0.60	0.60	0.59	0.56	0.52	0.35	0.25	0.19	0.21
$\sigma_L = 0.5$									
Separability	1.34	1.35	1.38	1.39	1.36	1.28	1.21	1.12	1.12
Substitutability	0.65	0.65	0.65	0.63	0.59	0.45	0.37	0.31	0.31
$\sigma_L = 1.0$									
Separability	1.51	1.54	1.60	1.62	1.59	1.54	1.49	1.39	1.38
Substitutability	0.79	0.81	0.84	0.84	0.81	0.73	0.67	0.60	0.60
$\sigma_L = 1.5$									
Separability	1.85	1.91	2.02	2.06	2.04	2.06	2.05	1.92	1.93
Substitutability	1.15	1.19	1.27	1.30	1.28	1.29	1.28	1.18	1.19

Note: Unless otherwise stated we use the benchmark parameter values. In the benchmark parameterization $\sigma_L = 1.0$

the substitutability world vis-à-vis the separable world. We also include an experiment that sets $log(v) = -1.0$, implying complementarity between public and private consumption. Here the utility specification matters a lot: very large multipliers are obtained under log utility and no habit formation whereas under the benchmark utility function the impact multiplier is very negative even though the output response is rapidly and strongly reversed after a few quarters in such a way that after 8 quarters the dynamic multipliers are above those obtained under substitutability. We have verified that under complementarity this initial impact is specific to the ZLB state; in normal times, larger multipliers are obtained even on impact.

Table 3

Dynamic Output Multipliers at the ZLB - Varying Degree of Substitutability C,G

Quarters	1	2	4	8	12	24	32	48	100
Benchmark Utility									
Separability	1.51	1.54	1.60	1.62	1.59	1.54	1.49	1.39	1.38
$log(v) = 7.9$ $\phi = 0.66$	0.79	0.81	0.84	0.84	0.81	0.73	0.67	0.60	0.60
$log(v) = 1.5$ $\phi = 0.66$	0.61	0.64	0.68	0.69	0.67	0.58	0.52	0.46	0.46
$log(v) = 0.65$ $\phi = 0.66$	0.31	0.37	0.44	0.49	0.47	0.38	0.32	0.27	0.26
$log(v) = -1.0$ $\phi = 0.66$	-2.27	-0.88	0.27	0.91	1.04	0.91	0.77	0.65	0.51
Log Utility, No Habit									
Separability	1.42	1.35	1.25	1.11	1.03	0.83	0.72	0.64	0.61
$log(v) = 7.9$ $\phi = 0.66$	0.67	0.62	0.55	0.47	0.40	0.19	0.09	0.05	0.03
$log(v) = 1.5$ $\phi = 0.66$	0.76	0.70	0.62	0.52	0.45	0.24	0.14	0.09	0.08
$log(v) = 0.65$ $\phi = 0.66$	0.94	0.87	0.78	0.66	0.58	0.38	0.27	0.21	0.20
$log(v) = -1.0$ $\phi = 0.66$	3.35	3.27	3.19	3.08	2.99	2.76	2.61	2.43	2.31

Note: Unless otherwise stated we use the benchmark parameter values and shocks. The standard parameters related to substitutability are $\phi = 0.66$ and $log(v) = 7.9$. The Log Utility, No Habit specification amounts to setting $\sigma_c = 1$ and $\theta = 0$

Regarding the settings related to fiscal policy (size and persistence of the government consumption shock, persistence of the tax rate and the speed of adjustment of debt towards the steady-state) we note the following (see Table 4): a) for sizes of the government spending shock implying an initial variation in spending between 0.5% and 2% of output the corresponding multipliers change very little compared to our benchmark experiment. Though a larger shock is associated with a stronger response of inflation (which lowers more the real interest rate and favors higher multipliers) there is a counteracting force driven by the increase in distortionary taxes needed to finance the larger spending shock; b) a higher persistence of the government spending shock (ρ_G) is associated with lower multipliers, contrary to the conventional result obtained in flexible price settings (see, e.g., Aiyagari et al., 1992 or Baxter and King, 1993) but consistent with what often is obtained when nominal rigidities are present (see e.g., Galí et al. 2007); c) the effect of a low (high) persistence of the tax rate ρ is very similar to that of a high (respectively, low) speed of adjustment of debt towards its steady state level. As we noted in Section 3.3, the lower is the speed of adjustment (or here, the higher is the persistence in the tax rate or the less it reacts to deviations of the debt ratio from its steady state), the higher are the multipliers as the distortionary effect of taxes on labor supply and investment is more muted. We include again as a reference what obtains if the adjustment of the debt ratio towards its steady state is made through lump-sum taxes (Ricardian model), noting that under a very persistent tax rate (when $\rho = 0.95$) output multipliers are somewhat higher than what obtains in the Ricardian world, reaching 1.36 after 32 quarters.

All in all, perhaps with the exception of the fiscal rule, our benchmark parameterization favors relatively high multipliers. Below, we analyze reasonable departures from this parameterization that lead to even larger multipliers under substitutability. This will give us a plausible range of multipliers that can be compared with the empirical literature.

Table 4

Dynamic Output Multipliers at the ZLB - Varying Financing and G parameters

Quarters	1	2	4	8	12	24	32	48	100
Benchmark: $\rho_G = 0.85$, $\rho = 0.92$, $\gamma = 0.094$, *G shock* 1% *Y*									
Separability	1.51	1.54	1.60	1.62	1.59	1.54	1.49	1.39	1.38
Substitutability	0.79	0.81	0.84	0.84	0.81	0.73	0.67	0.60	0.60
Persistence G shock (ρ_G)									
$\rho_G = 0.97$									
Separability	1.32	1.29	1.24	1.12	1.01	0.78	0.66	0.49	0.29
Substitutability	0.57	0.54	0.50	0.42	0.36	0.19	0.10	-0.02	-0.15
$\rho_G = 0.99$									
Separability	1.10	1.04	0.96	0.85	0.77	0.61	0.52	0.39	0.23
Substitutability	0.34	0.29	0.23	0.17	0.14	0.03	-0.03	-0.11	-0.20
Speed of Adjustment (γ)									
$\gamma = 0.024$									
Separability	1.67	1.72	1.81	1.84	1.79	1.74	1.75	1.73	1.70
Substitutability	1.07	1.13	1.23	1.26	1.23	1.20	1.21	1.21	1.19
$\gamma = 0.164$									
Separability	1.39	1.40	1.42	1.41	1.37	1.23	1.14	1.05	1.01
Substitutability	0.69	0.69	0.70	0.67	0.62	0.45	0.37	0.34	0.30
Ricardian Model									
Separability	1.65	1.70	1.79	1.80	1.74	1.64	1.63	1.63	1.64
Substitutability	1.06	1.11	1.20	1.23	1.19	1.11	1.11	1.12	1.14
Persistence Fiscal Rule (ρ)									
$\rho = 0.80$									
Separability	1.36	1.37	1.39	1.36	1.31	1.16	1.09	1.04	1.00
Substitutability	0.67	0.67	0.67	0.64	0.58	0.44	0.38	0.36	0.35
$\rho = 0.85$									
Separability	1.39	1.40	1.43	1.41	1.36	1.23	1.16	1.09	1.06
Substitutability	0.70	0.70	0.72	0.69	0.64	0.51	0.45	0.42	0.41
$\rho = 0.95$									
Separability	1.68	1.74	1.83	1.88	1.87	1.90	1.92	1.86	1.85
Substitutability	1.09	1.15	1.24	1.29	1.29	1.34	1.36	1.30	1.31
Size Gov't Spending Shock									
G shock 2% *Y*									
Separability	1.46	1.48	1.53	1.53	1.50	1.43	1.38	1.28	1.27
Substitutability	0.83	0.85	0.89	0.90	0.87	0.80	0.75	0.68	0.68
Gshock 1.5% *Y*									
Separability	1.48	1.51	1.56	1.57	1.54	1.48	1.43	1.33	1.32
Substitutability	0.83	0.85	0.89	0.90	0.87	0.80	0.75	0.68	0.68
G shock 0.5% *Y*									
Separability	1.54	1.57	1.64	1.65	1.63	1.58	1.54	1.44	1.43
Substitutability	0.82	0.85	0.89	0.89	0.87	0.79	0.74	0.67	0.68

Note: Unless otherwise stated we use the benchmark parameter values. The Government Spending Process and the Fiscal rule are as follows: $G_t = (1 - \rho_G)G_{ss} + \rho_G G_{t-1} + \eta_t^G$; $\tau_t = (1-\rho)\tau_{ss} + \rho\tau_{t-1} + (1-\rho)\gamma\left(\frac{B_{t-1}}{Y_{t-1}} - b_{ss}\right)$

3.5 Large(r) multipliers under substitutability

Table 5

Dynamic Output Multipliers at the ZLB - Towards Larger Multipliers

Quarters	1	2	4	8	12	24	32	48	100
Benchmark									
Separability	1.51	1.54	1.60	1.62	1.59	1.54	1.49	1.39	1.38
Substitutability	0.79	0.81	0.84	0.84	0.81	0.73	0.67	0.60	0.60
Longer ZLB period: β shock 0.178									
Separability	1.97	2.00	2.09	2.16	2.19	2.35	2.37	2.21	2.22
Substitutability	1.15	1.16	1.20	1.23	1.25	1.35	1.35	1.22	1.24
Longer ZLB period, Low G shock: β shock 0.178, G *shock* 0.5% Y									
Separability	2.08	2.10	2.20	2.27	2.31	2.53	2.56	2.38	2.40
Substitutability	1.20	1.20	1.24	1.27	1.30	1.43	1.44	1.29	1.31
High Persistence Fiscal Rule, Low G shock: $\rho = 0.95$, G *shock* 0.5% Y									
Separability	1.79	1.86	1.98	2.05	2.04	2.12	2.17	2.11	2.10
Substitutability	1.23	1.30	1.42	1.49	1.50	1.60	1.65	1.61	1.62

Note: Unless otherwise stated we use the benchmark parameter values and shocks.

The aim of this Section is to show that our model is able to generate large multipliers and that the substitutability mechanism still affects significantly these multipliers.

Table 5 shows several simulations driven by the insights of some of the robustness exercises above. We confirm that the magnitude of the multipliers increases (decreases) with the size of the discount factor (government spending) shock and with the persistence (measured by ρ) of the tax rate within the debt stabilizing fiscal rule. Quantitatively, these simulations generate output multipliers substantially larger than those obtained within the benchmark parameterization. In particular, most multipliers under separability are above 2 while under substitutability they are above 1.2, on average, and often substantially larger than that. For example, under a smaller size for the government spending shock (0.5% of GDP) and a higher discount factor shock (implying an economy staying longer in the ZLB state), we obtain the following results: after roughly 30 quarters from the occurrence of the fiscal shock, multipliers are as high as 2.5 and 1.4 under the separability and substitutability cases, respectively. The first mentioned figure is similar to that reported in CER (2011) who, treating private and government consumption as separable in preferences, obtain benchmark multipliers as high as 2.3. The second figure is in line with the recent empirical evidence of Ramey and Zubairy (2018) who find upper bound estimates for the output multiplier of roughly 1.5 at the ZLB. Finally, notice that in this particular simulation, the part of the multiplier explained by the substitutability mechanism amounts to roughly 1.1 which is somewhat larger than the same measure obtained within the benchmark parameterization.

All in all, we conclude that the taming effect of substitutability is preserved and often enhanced even when the multipliers are large under separability.

4 Conclusions

In this paper, we have challenged the typical large size of government spending multipliers obtained when the ZLB binds the nominal interest rate, conditional on a liquidity trap caused by a preference shock.

In particular, we have shown that using a set-up similar to that of CER(2011) –but allowing for substitutability between private and government consumption– generates output multipliers around unity which are close to the ones measured by some recent empirical papers. In particular, the substitutability channel limits the fall in the real interest rate during the ZLB periods. Our finding is robust to the consideration of different taxation schemes.

This paper contributes to the current academic debate that aims at better understanding and carefully measuring the effects of fiscal policy when the nominal interest rate is at ZLB. Further, given our focus on the role of government spending in agents' preferences, our results can inform analyses of the desirability of a government spending expansion during the ZLB episode.

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Appendix A: Equilibrium Conditions

We restrict attention to the model with distortionary taxation. The version with lump-sum taxation obtains by setting all marginal tax rates equal to zero and by balancing the budget. Equilibrium conditions follow from the first order conditions (F.O.C.s) of households' and firms' problems while imposing symmetry, fiscal policy equations, market clearing conditions and processes for the exogenous shocks. The Lagrange multipliers associated with the budget constraint and the capital accumulation equation are, respectively, μ_t and q_t (Tobin's q).

- *Aggregator (consumption):*

$$\widetilde{C}_t = \left[\phi\left(C_t\right)^{\frac{\upsilon-1}{\upsilon}} + (1-\phi)\left(G_t\right)^{\frac{\upsilon-1}{\upsilon}}\right]^{\frac{\upsilon}{\upsilon-1}} \tag{11}$$

- *Consumption F.O.C.:*

$$(1+\tau^c)\mu_t = e^{\lambda_t}\left[\phi\left(\frac{\widetilde{C}_t}{C_t}\right)^{\frac{1}{\upsilon}}\left[\left(\widetilde{C}_t - \gamma\widetilde{C}_{t-1}\right)^{-1}\right]\right] \tag{12}$$

- *Labor supply F.O.C.:*

$$\mu_t = \frac{e^{\lambda_t}\chi L_t^{\sigma_n}}{(1-\tau_t)W_t} \tag{13}$$

- *Risk-free asset F.O.C.:*

$$\beta E_t\left[\frac{\mu_{t+1}}{\mu_t}\frac{R_t}{\pi_{t+1}}\right] = 1 \tag{14}$$

- *Investment F.O.C.:*

$$\begin{aligned}\mu_t = \mu_t q_t E_t &\left\{\left[1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] - \frac{I_t}{I_{t-1}}\kappa\left(\frac{I_t}{I_{t-1}} - 1\right)\right\} + \\ &+ \beta e^{\lambda_t} E_t\left[\mu_{t+1}q_{t+1}\left(\frac{I_{t+1}}{I_t}\right)^2\kappa\left(\frac{I_{t+1}}{I_t} - 1\right)\right]\end{aligned} \tag{15}$$

- *Next period capital F.O.C.:*

$$\mu_t q_t = E_t\left[\beta e^{\lambda_t}\mu_{t+1} r_{t+1}^k u_{t+1} - a\left(u_{t+1}\right)\right](1-\tau_t) + q_{t+1}\left(1-\delta\right)\right] \tag{16}$$

where $a(u_t) = \gamma_1 (u_t - 1) + \frac{\gamma_2}{2} (u_t - 1)^2$ represents the cost of using capital at intensity u_t.

- *Capital law of motion:*

$$K_{t+1} = (1 - \delta) K_t + I_t \left[1 - \frac{\kappa}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] \tag{17}$$

- *Capacity utilization F.O.C.:*

$$r_t^k = a'(u_t) = \gamma_1 + \gamma_2 (u_t - 1) \tag{18}$$

- *Marginal rate of substitution consumption/labor:*

$$mrs_t = \frac{\chi L_t^{\sigma_n}}{(1 + \tau^c)\lambda_t} \tag{19}$$

- *Wage markup:*

$$\lambda_{w,t} = \frac{w_t(1 - \tau_t)}{mrs_t} \tag{20}$$

- *Production function:*

$$Y_t = (u_t k_t)^{\alpha} (L_t)^{1-\alpha} - \Phi \tag{21}$$

- *Factor demands:*

$$(1 - \alpha) \frac{Y_t}{L_t(1 + \lambda_{p,ss})} = W_t \tag{22}$$

$$\alpha \frac{Y_t}{K_t(1 + \lambda_{p,ss})} = u_t r_t^k \tag{23}$$

- *Marginal cost:*

$$MC_t = \frac{\left(u_t r_t^k\right)^{\alpha} W_t^{1-\alpha}}{\alpha^{\alpha} (1 - \alpha)^{1-\alpha}} \tag{24}$$

- *Price markup:*

$$\frac{1}{MC_t} = \lambda_{p,t} \tag{25}$$

- *Taylor Rule*

$$R_t = \max(Z_t, 1), \quad \text{where} \quad Z_t = (Z_{t-1})^{\alpha_z} (\pi_t - 1)^{\phi_\pi(1-\alpha_z)} * \left(\frac{Y_t}{Y_{t-1}} - 1\right)^{\phi_y(1-\alpha_z)} \tag{26}$$

- *Fiscal Rule*

$$\tau_t = (1-\rho)\tau_{ss} + \rho\tau_{t-1} + (1-\rho)\gamma\left(\frac{B_{t-1}}{Y_{t-1}} - b_{ss}\right), \tag{27}$$

  where τ_{ss} and b_{ss} are the steady-state values of τ_t and $\frac{B_t}{Y_t}$, respectively.

- *Government Budget Constraint*

$$G_t + \frac{R_{t-1}}{\pi_t} B_{t-1} = B_t + \tau^c C_t + \tau_t \frac{W_t}{P_t} L_t + \tau_t \left[r_t^k u_t - a(u_t)\right] K_t + T_{ss} \tag{28}$$

- *Market Clearing*

$$Y_t = C_t + I_t + G_t + a(u_t) K \tag{29}$$

- *Shocks processes:*

$$G_t = (1-\rho_G) G_{ss} + \rho_G G_{t-1} + \eta_t^G \tag{30}$$

$$\lambda_t = \rho_\lambda \lambda_{t-1} + \eta_t^\lambda$$

Finally, following SGU (2006) we report the equilibrium conditions related to wage and price setting, expressed in recursive form:

- f_1

$$f_t^1 = \mu_t (1-\tau_t) L_t \left(\frac{W_t}{\widetilde{W}_t}\right)^{\varepsilon_w} + \left(\xi_w \beta e^{\lambda_t}\right) \left(\frac{\widetilde{W}_{t+1}}{\widetilde{W}_t}\right)^{\varepsilon_w} \pi_{t+1}^{\varepsilon_w} f_{t+1}^1$$

  where $\widetilde{W}_t$ is the wage in t, if set optimally.

- f_2

$$f_t^2 = \frac{\mu_t (1-\tau_t)}{\lambda_{w,t}} L_t \left(\frac{W_t}{\widetilde{W}_t}\right)^{\varepsilon_w + 1} + \left(\xi_w \beta e^{\lambda_t}\right) \left(\frac{\widetilde{W}_{t+1}}{\widetilde{W}_t}\right)^{\varepsilon_w + 1} \pi_{t+1}^{\varepsilon_w} f_{t+1}^2$$

- *Wage aggregator* $\tilde{W}$

$$(1-\varepsilon_w) \widetilde{W}_t f_t^1 + \varepsilon_w f_t^2 = 0$$

- *Wage aggregator W*

$$W_t^{1-\varepsilon_w} = \xi_w \pi_t^{\varepsilon_w - 1} W_{t-1}^{1-\varepsilon_w} + (1-\xi_w)\widetilde{W}_t^{1-\varepsilon_w}$$

- x_1

$$x_t^1 = MC_t \left(\tilde{p}_t\right)^{-1-\varepsilon} Y_t + E_t \xi_p \frac{\mu_{t+1}}{\mu_t} \left[\left(\frac{\tilde{p}_t}{\tilde{p}_{t+1}} \right)^{-1-\varepsilon} \pi_{t+1}^{\varepsilon} \right] x_{t+1}^1$$

where $\tilde{p}_t$ is the wage in t, if set optimally.

- x_2

$$x_t^2 = \left(\tilde{p}_t\right)^{-\varepsilon} Y_t + E_t \xi_p \beta e^{\lambda_t} \frac{\mu_{t+1}}{\mu_t} \left(\frac{\tilde{p}_t}{\tilde{p}_{t+1}} \right)^{-\varepsilon} \pi_{t+1}^{\varepsilon-1} x_{t+1}^2$$

- *Price aggregator 1*

$$\varepsilon x_t^1 + (1-\varepsilon)\, x_t^2 = 0$$

- *Price aggregator 2*

$$1 = \xi_p (\pi_t)^{\eta-1} + (1-\xi_p) \tilde{p}_t^{1-\varepsilon}$$

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2018

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