

# When is the Government Spending Multiplier Large?\*

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## Abstract

We argue that the government-spending multiplier can be much larger than one when the zero lower bound on the nominal interest rate binds. The larger is the fraction of government spending that occurs while the nominal interest rate is zero, the larger is the value of the multiplier. After providing intuition for these results, we investigate the size of the multiplier in a dynamic, stochastic, general equilibrium model. In this model the multiplier effect is substantially larger than one when the zero bound binds. Our model is consistent with the behavior of key macro aggregates during the recent financial crisis.

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## 1. Introduction

A classic question in macroeconomics is: what is the size of the government-spending multiplier? There is a large empirical literature that grapples with this question. Authors such as Barro (1981) argue that the multiplier is around 0.8 while authors such as Ramey (2008) estimate the multiplier to be closer to 1.2.<sup>1</sup> There is also a large literature that uses general-equilibrium models to study the size of the government-spending multiplier. In standard new-Keynesian models the government-spending multiplier can be somewhat above or below one depending on the exact specification of agent's preferences (see Gali, López-Salido, and Vallés (2007) and Monacelli and Perotti (2008)). In frictionless real-business-cycle models this multiplier is typically less than one (see e.g. Aiyagari, Christiano, and Eichenbaum (1992), Baxter and King (1993), Burnside, Eichenbaum and Fisher (2004), Ramey and Shapiro (1998), and Ramey (2011)). Viewed overall it is hard to argue, based on the literature, that the government-spending multiplier is substantially larger than one.

In this paper we argue that the government-spending multiplier can be much larger than one when the nominal interest rate does not respond to an increase in government spending. We develop this argument in a model where the multiplier is quite modest if the nominal interest rate is governed by a Taylor rule. When such a rule is operative the nominal interest rate rises in response to an expansionary fiscal policy shock that puts upward pressure on output and inflation.

There is a natural scenario in which the nominal interest rate does not respond to an increase in government spending: when the zero lower bound on the nominal interest rate binds. We find that the multiplier is very large in economies where

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<sup>1</sup>For recent contributions to the VAR-based empirical literature on the size of the government-spending multiplier see Fisher and Peters (2010) and Ilzetzki, Mendoza, and Vegh (2009). Hall (2009) provides an analysis and review of the empirical literature.

the output cost of being in the zero-bound state is also large. In such economies it can be socially optimal to substantially raise government spending in response to shocks that make the zero lower bound on the nominal interest rate binding.

We begin by considering an economy with Calvo-style price frictions, no capital and a monetary authority that follows a standard Taylor rule. Building on Eggertsson and Woodford (2003) we study the effect of a temporary, unanticipated rise in agents' discount factor. Other things equal, the shock to the discount factor increases desired saving. Since investment is zero in this economy, aggregate saving must be zero in equilibrium. When the shock is small enough, the real interest rate falls and there is a modest decline in output. However, when the shock is large enough, the zero bound becomes binding before the real interest rate falls by enough to make aggregate saving zero. In this model, the only force that can induce the fall in saving required to re-establish equilibrium is a large, transitory fall in output.

Why is the fall in output so large when the economy hits the zero bound? For a given fall in output, marginal cost falls and prices decline. With staggered pricing, the drop in prices leads agents to expect future deflation. With the nominal interest rate stuck at zero, the real interest rate rises. This perverse rise in the real interest rate leads to an increase in desired saving which partially undoes the effect of a given fall in output. So, the total fall in output required to reduce desired saving to zero is very large.

This scenario resembles the paradox of thrift originally emphasized by Keynes (1936) and recently analyzed by Krugman (1998), Eggertsson and Woodford (2003), and Christiano (2004). In the textbook version of this paradox, prices are constant and an increase in desired saving lowers equilibrium output. But, in contrast to the textbook scenario, the zero-bound scenario studied in the modern literature involves a deflationary spiral which contributes to and accompanies the

large fall in output.

Consider now the effect of an increase in government spending when the zero bound is strictly binding. This increase leads to a rise in output, marginal cost and expected inflation. With the nominal interest rate stuck at zero, the rise in expected inflation drives down the real interest rate, which drives up private spending. This rise in spending leads to a further rise in output, marginal cost, and expected inflation and a further decline in the real interest rate. The net result is a large rise in output and a large fall in the rate of deflation. In effect, the increase in government consumption counteracts the deflationary spiral associated with the zero-bound state.

The exact value of the government-spending multiplier depends on a variety of factors. However, we show that this multiplier is large in economies in which the output cost associated with the zero-bound problem is more severe. We argue this point in two ways. First, we show that the value of the government-spending multiplier can depend sensitively on the model's parameter values. But, parameter values which are associated with large declines in output when the zero bound binds are also associated with large values of the government-spending multiplier. Second, we show that the value of the government-spending multiplier is positively related to how long the zero bound is expected to bind.

An important practical objection to using fiscal policy to counteract a contraction associated with the zero-bound state is that there are long lags in implementing increases in government spending. Motivated by this consideration, we study the size of the government-spending multiplier in the presence of implementation lags. We find that a key determinant of the size of the multiplier is the state of the world in which new government spending comes on line. If it comes on line in future periods when the nominal interest rate is zero then there is a large effect on current output. If it comes on line in future periods where the nominal interest

rate is positive, then the current effect on government spending is smaller. So our analysis supports the view that, for fiscal policy to be effective, government spending must come online in a timely manner.

In the second step of our analysis we incorporate capital accumulation into the model. For computational reasons we consider temporary shocks that make the zero bound binding for a deterministic number of periods. Again, we find that the government-spending multiplier is larger when the zero bound binds. Allowing for capital accumulation has two effects. First, for a given size shock it reduces the likelihood that the zero bound becomes binding. Second, when the zero bound binds, the presence of capital accumulation tends to increase the size of the government-spending multiplier. The intuition for this result is that, in our model, investment is a decreasing function of the real interest rate. When the zero bound binds, the real interest rate generally rises. So, other things equal, saving and investment diverge as the real interest rate rises, thus exacerbating the meltdown associated with the zero bound. As a result, the fall in output necessary to bring saving and investment into alignment is larger than in the model without capital.

The simple models discussed above suggest that the multiplier can be large in the zero-bound state. The obvious next step would be to use reduced form methods, such as identified VARs, to estimate the government-spending multiplier when the zero bound binds. Unfortunately, this task is fraught with difficulties. First, we cannot mix evidence from states where the zero bound binds with evidence from other states because the multipliers are very different in the two states. Second, we have to identify exogenous movements in government spending when the zero bound binds.<sup>2</sup> This task seems daunting at best. Almost surely gov-

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<sup>2</sup>To see how critical this step is, suppose that the government chooses spending to keep output exactly constant in the face of shocks that make the zero bound bind. A naive econometrician who simply regressed output on government spending would falsely conclude that the

ernment spending would rise in response to large output losses in the zero-bound state. To know the government spending multiplier we need to know what output would have been had government spending not risen. For example, the simple observation that output did not grow quickly in Japan in the zero-bound state, even though there were large increases in government spending, tells us nothing about the question of interest.

Given these difficulties, we investigate the size of the multiplier in the zero-bound state using the empirically plausible DSGE model proposed by Altig, Christiano, Eichenbaum and Lindé (2011) (henceforth ACEL). This model incorporates price and wage setting frictions, habit formation in consumption, variable capital utilization and investment adjustment costs of the sort proposed by Christiano, Eichenbaum and Evans (2005) (henceforth CEE). ACEL estimate the parameters of their model to match the impulse response function of ten macro variables to a monetary shock, a neutral technology shock, and a capital-embodied technology shock.

Our key findings based on the ACEL model can be summarized as follows. First, when the central bank follows a Taylor rule, the value of the government-spending multiplier is generally less than one. Second, the multiplier is much larger if the nominal interest rate does not respond to the rise in government spending. For example, suppose that government spending goes up for 12 quarters and the nominal interest rate remains constant. In this case the impact multiplier is roughly 1.6 and has a peak value of about 2.3. Third, the value of the multiplier depends critically on how much government spending occurs in the period during which the nominal interest rate is constant. The larger is the fraction of government spending that occurs while the nominal interest rate is constant, the 

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government spending multiplier is zero. This example is, of course, just an application of Tobin's (1970) post hoc ergo propter hoc argument.

smaller is the value of the multiplier. Consistent with the theoretical analysis above, this result implies that for government spending to be a powerful weapon in combating output losses associated with the zero-bound state, it is critical that the bulk of the spending come on line when the lower bound is actually binding. Fourth, we find that the model generates sensible predictions for the current crisis under the assumption that the zero bound binds. In particular the model does well at accounting for the behavior of output, consumption, investment, inflation, and short-term nominal interest rates.

As emphasized by Eggertsson and Woodford (2003), an alternative way to escape the negative consequences of a shock that makes the zero bound binding is for the central bank to commit to future inflation. We abstract from this possibility in this paper. We do so for a number of reasons. First, this theoretical possibility is well understood. Second, we do not think that it is easy in practice for the central bank to credibly commit to future high inflation. Third, the optimal trade-off between higher government purchases and anticipated inflation depends sensitively on how agents value government purchases and the costs of anticipated inflation. Studying this issue is an important topic for future research.

Our analysis builds on Christiano (2004) and Eggertsson (2004) who argue that increasing government spending is very effective when the zero bound binds. Eggertsson (2011) analyzes both the effects of increases in government spending and transitory tax cuts when the zero bound binds. The key contributions of this paper are to analyze the size of the multiplier in a medium-size DSGE model, study the model's performance in the financial crisis that began in 2008, and quantify the importance of the timing of government spending relative to the timing of the zero bound.

Our analysis is related to several recent papers on the zero bound. Bodenstein, Erceg, and Guerrieri (2009) analyze the effects of shocks to open economies when

the zero bound binds. Braun and Waki (2006) use a model in which the zero bound binds to account for Japan’s experience in the 1990s. Their results for fiscal policy are broadly consistent with our results. Braun and Waki (2006) and Coenen and Wieland (2003) investigate whether alternative monetary policy rules could have avoided the zero bound state in Japan.

Our paper is organized as follows. In section 2 we analyze the size of the government-spending multiplier when the interest follows a Taylor rule in a standard new-Keynesian model without capital. In section 3 we modify the analysis to assume that the nominal interest rate does not respond to an increase in government spending, say because the lower bound on the nominal interest rate binds. In section 4 we extend the model to incorporate capital. In section 5 we discuss the properties of the government-spending multiplier in the medium size DSGE model proposed by ACEL and investigate the performance of the model during the recent financial crisis. Section 6 investigates the sensitivity of our conclusions to the presence of distortionary taxes. Section 7 concludes.

## 2. The standard multiplier in a model without capital

In this section we present a simple new-Keynesian model and analyze its implications for the size of the “standard multiplier,” by which we mean the size of the government-spending multiplier when the nominal interest rate is governed by a Taylor rule.

**Households** The economy is populated by a representative household, whose life-time utility,  $U$ , is given by:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{[C_t^\gamma (1 - N_t)^{1-\gamma}]^{1-\sigma} - 1}{1 - \sigma} + v(G_t) \right]. \quad (2.1)$$



Here  $E_0$  is the conditional expectation operator, and  $C_t$ ,  $G_t$ , and  $N_t$  denote time- $t$  consumption, government consumption, and hours worked, respectively. We assume that  $\sigma > 0$ ,  $\gamma \in (0, 1)$ , and that  $v(\cdot)$  is a concave function.

The household budget constraint is given by:

$$P_t C_t + B_{t+1} = B_t (1 + R_t) + W_t N_t + T_t, \quad (2.2)$$

where  $T_t$  denotes firms' profits net of lump-sum taxes paid to the government. The variable  $B_{t+1}$  denotes the quantity of one-period bonds purchased by the household at time  $t$ . Also,  $P_t$  denotes the price level and  $W_t$  denotes the nominal wage rate. Finally,  $R_t$  denotes the one-period nominal rate of interest that pays off in period  $t$ . The household's problem is to maximize utility given by equation (2.1) subject to the budget constraint given by equation (2.2) and the condition  $E_0 \lim_{t \rightarrow \infty} B_{t+1} / [(1 + R_0)(1 + R_1) \dots (1 + R_t)] \geq 0$ .

**Firms** The final good is produced by competitive firms using the technology,

$$Y_t = \left( \int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}, \quad \varepsilon > 1, \quad (2.3)$$

where  $Y_t(i)$ ,  $i \in [0, 1]$  denotes intermediate good  $i$ .

Profit maximization implies the following first-order condition for  $Y_t(i)$ :

$$P_t(i) = P_t \left( \frac{Y_t}{Y_t(i)} \right)^{\frac{1}{\varepsilon}}, \quad (2.4)$$

where  $P_t(i)$  denotes the price of intermediate good  $i$  and  $P_t$  is the price of the homogeneous final good.

The intermediate good,  $Y_t(i)$ , is produced by a monopolist using the following technology:

$$Y_t(i) = N_t(i),$$

where  $N_t(i)$  denotes employment by the  $i^{\text{th}}$  monopolist. We assume there is no entry or exit into the production of the  $i^{\text{th}}$  intermediate good. The monopolist is subject to Calvo-style price-setting frictions and can optimize its price,  $P_t(i)$ , with probability  $1 - \theta$ . With probability  $\theta$  the firm sets:

$$P_t(i) = P_{t-1}(i).$$

The discounted profits of the  $i^{\text{th}}$  intermediate good firm are:

$$E_t \sum_{j=0}^{\infty} \beta^j v_{t+j} [P_{t+j}(i) Y_{t+j}(i) - (1 - \nu) W_{t+j} N_{t+j}(i)], \quad (2.5)$$

where  $\nu = 1/\varepsilon$  denotes an employment subsidy which corrects, in steady state, the inefficiency created by the presence of monopoly power. The variable  $v_{t+j}$  is the multiplier on the household budget constraint in the Lagrangian representation of the household problem. The variable  $W_{t+j}$  denotes the nominal wage rate.

Firm  $i$  maximizes its discounted profits, given by equation (2.5), subject to the Calvo price-setting friction, the production function, and the demand function for  $Y_t(i)$ , given by equation (2.4).

**Monetary policy** We assume that monetary policy follows the rule:

$$R_{t+1} = \max(Z_{t+1}, 0), \quad (2.6)$$

where

$$Z_{t+1} = (1/\beta)(1 + \pi_t)^{\phi_1(1-\rho_R)}(Y_t/Y)^{\phi_2(1-\rho_R)} [\beta(1 + R_t)]^{\rho_R} - 1.$$

Throughout the paper a variable without a time subscript denotes its steady state value, e.g. the variable  $Y$  denotes the steady-state level of output. The variable  $\pi_t$  denotes the time- $t$  rate of inflation. We assume that  $\phi_1 > 1$  and  $\phi_2 \in (0, 1)$ .

According to equation (2.6) the monetary authority follows a Taylor rule as long as the implied nominal interest rate is non-negative. Whenever the Taylor rule implies a negative nominal interest rate, the monetary authority simply sets the nominal interest rate to zero. For convenience we assume that steady-state inflation is zero. This assumption implies that the steady-state net nominal interest rate is  $1/\beta - 1$ .

**Fiscal policy** As long as the zero bound on the nominal interest rate is not binding, government spending evolves according to:

$$G_{t+1} = G_t^{\rho} \exp(\eta_{t+1}). \quad (2.7)$$

Here  $G$  is the level of government spending in the non-stochastic steady state and  $\eta_{t+1}$  is an i.i.d. shock with zero mean. To simplify our analysis, we assume that government spending and the employment subsidy are financed with lump-sum taxes. The exact timing of these taxes is irrelevant because Ricardian equivalence holds under our assumptions. We discuss the details of fiscal policy when the zero bound binds in Section 3.

**Equilibrium** The economy's resource constraint is:

$$C_t + G_t = Y_t. \quad (2.8)$$

A 'monetary equilibrium' is a collection of stochastic processes,

$$\{C_t, N_t, W_t, P_t, Y_t, R_t, P_t(i), Y_t(i), N_t(i), v_t, B_{t+1}, \pi_t\},$$

such that for given  $\{G_t\}$  the household and firm problems are satisfied, the monetary and fiscal policy rules are satisfied, markets clear, and the aggregate resource constraint is satisfied.

To solve for the equilibrium we use a linear approximation around the non-stochastic steady state of the economy. Throughout,  $\hat{Z}_t$  denotes the percentage deviation of  $Z_t$  from its non-stochastic steady state value,  $Z$ . The equilibrium is characterized by the following set of equations.

The Phillips curve for this economy is given by:

$$\pi_t = E_t \left( \beta \pi_{t+1} + \kappa \widehat{MC}_t \right), \quad (2.9)$$

where  $\kappa = (1 - \theta)(1 - \beta\theta)/\theta$ . In addition,  $MC_t$  denotes real marginal cost which, under our assumptions, is equal to the real wage rate. Absent labor market frictions, the percent deviation of real marginal cost from its steady state value is given by:

$$\widehat{MC}_t = \hat{C}_t + \frac{N}{1 - N} \hat{N}_t. \quad (2.10)$$

The linearized intertemporal Euler equation for consumption is:

$$\begin{aligned} & [\gamma(1 - \sigma) - 1] \hat{C}_t - (1 - \gamma)(1 - \sigma) \frac{N}{1 - N} \hat{N}_t \\ &= E_t \left\{ \beta (R_{t+1} - R) - \pi_{t+1} + [\gamma(1 - \sigma) - 1] \hat{C}_{t+1} - (1 - \gamma)(1 - \sigma) \frac{N}{1 - N} \hat{N}_{t+1} \right\} \end{aligned} \quad (2.11)$$

The linearized aggregate resource constraint is:

$$\hat{Y}_t = (1 - g) \hat{C}_t + g \hat{G}_t, \quad (2.12)$$

where  $g = G/Y$ .

Combining equations (2.9) and (2.10) and using the fact that  $\hat{N}_t = \hat{Y}_t$  we obtain:

$$\pi_t = \beta E_t (\pi_{t+1}) + \kappa \left[ \left( \frac{1}{1 - g} + \frac{N}{1 - N} \right) \hat{Y}_t - \frac{g}{1 - g} \hat{G}_t \right]. \quad (2.13)$$

Similarly, combining equations (2.11) and (2.12) and using the fact that  $\hat{N}_t = \hat{Y}_t$  we obtain:

$$\begin{aligned} \hat{Y}_t - g[\gamma(\sigma - 1) + 1]\hat{G}_t = & \quad (2.14) \\ E_t \left\{ - (1 - g)[\beta(R_{t+1} - R) - \pi_{t+1}] + \hat{Y}_{t+1} - g[\gamma(\sigma - 1) + 1]\hat{G}_{t+1} \right\}. \end{aligned}$$

As long as the zero bound on the nominal interest rate does not bind, the linearized monetary policy rule is given by:

$$R_{t+1} - R = \rho_R(R_t - R) + \frac{1 - \rho_R}{\beta} (\phi_1 \pi_t + \phi_2 \hat{Y}_t).$$

Whenever the zero bound binds,  $R_{t+1} = 0$ .

We solve for the equilibrium using the method of undetermined coefficients. For simplicity, we begin by considering the case in which  $\rho_R = 0$ . Under the assumption that  $\phi_1 > 1$ , there is a unique linear equilibrium in which  $\pi_t$  and  $\hat{Y}_t$  are given by:

$$\pi_t = A_\pi \hat{G}_t, \quad (2.15)$$

$$\hat{Y}_t = A_Y \hat{G}_t. \quad (2.16)$$

The coefficients  $A_\pi$  and  $A_Y$  are given by:

$$A_\pi = \frac{\kappa}{1 - \beta\rho} \left[ \left( \frac{1}{1 - g} + \frac{N}{1 - N} \right) A_Y - \frac{g}{1 - g} \right], \quad (2.17)$$

$$A_Y = g \frac{(\rho - \phi_1)\kappa - [\gamma(\sigma - 1) + 1](1 - \rho)(1 - \beta\rho)}{(1 - \beta\rho)[\rho - 1 - (1 - g)\phi_2] + (1 - g)(\rho - \phi_1)\kappa \left( \frac{1}{1 - g} + \frac{N}{1 - N} \right)}. \quad (2.18)$$

**The effect of an increase in government spending** Using equation (2.12) we can write the government-spending multiplier as:

$$\frac{dY_t}{dG_t} = \frac{1}{g} \frac{\hat{Y}_t}{\hat{G}_t} = 1 + \frac{1 - g}{g} \frac{\hat{C}_t}{\hat{G}_t}. \quad (2.19)$$

This equation implies that the multiplier is less than one whenever consumption falls in response to an increase in government spending. Equation (2.16) implies that the government-spending multiplier is given by:

$$\frac{dY_t}{dG_t} = \frac{A_Y}{g}. \quad (2.20)$$

To analyze the magnitude of the multiplier outside of the zero bound we consider the following baseline parameter values:

$$\theta = 0.85, \beta = 0.99, \phi_1 = 1.5, \phi_2 = 0, \gamma = 0.29, g = 0.2, \sigma = 2, \rho_R = 0, \rho = 0.8. \quad (2.21)$$

These parameter values imply that  $\kappa = 0.03$  and  $N = 1/3$ . Our baseline parameter values imply that the government-spending multiplier is 1.05.

In our model Ricardian equivalence holds. From the perspective of the representative household, the increase in the present value of taxes equals the increase in the present value of government purchases. In a typical version of the standard neoclassical model we would expect some rise in output driven by the negative wealth effect on leisure of the tax increase. But in that model the multiplier is generally less than one because the wealth effect reduces private consumption. From this perspective it is perhaps surprising that the multiplier in our baseline model is greater than one. This perspective neglects two key features of our model: the frictions in price setting and the complementarity between consumption and leisure in preferences. When government purchases increase, total demand,  $C_t + G_t$ , increases. Since prices are sticky, price over marginal cost falls after a rise in demand. As emphasized in the literature on the role of monopoly power in business cycles, the fall in the markup induces an outward shift in the labor demand curve. This shift amplifies the rise in employment following the rise in demand. Given our specification of preferences,  $\sigma > 1$  implies that the marginal utility of consumption rises with the increase in employment. As long as

this increase in marginal utility is large enough, it is possible for private consumption to actually rise in response to an increase in government purchases. Indeed, consumption does rise in our benchmark scenario which is why the multiplier is larger than one.

To assess the importance of our preference specification we redid our calculations using the basic specification for the momentary utility function commonly used in the new-Keynesian DSGE literature:

$$u = (C_t^{1-\varsigma} - 1) / (1 - \varsigma) - \eta N_t^{1+\vartheta} / (1 + \vartheta), \quad (2.22)$$

where,  $\varsigma$ ,  $\eta$ , and  $\vartheta$  are positive. The key feature of this specification is that the marginal utility of consumption is independent of hours worked. Consistent with the intuition discussed above, we found that, across a wide set of parameter values,  $dY/dG$  is always less than one with this preference specification.<sup>3</sup>

To provide additional intuition for the determinants of the multiplier, we calculate  $dY/dG$  for various parameter configurations. In each case we perturb one parameter at a time relative to the benchmark parameter values. Our results can be summarized as follows. First, we find that the multiplier is an increasing function of  $\sigma$ . This result is consistent with the intuition above which builds on the observation that the marginal utility of consumption is increasing in hours worked. This dependence is stronger the higher is  $\sigma$ .

Second, the multiplier is a decreasing function of  $\kappa$ . In other words, the multiplier is larger the higher is the degree of price stickiness. This result reflects the fall in the markup when aggregate demand and marginal cost rise. This effect is stronger the stickier are prices. The multiplier exceeds one for all  $\kappa < 0.13$ . In the limiting case when prices are perfectly sticky ( $\kappa = 0$ ) the multiplier is given

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<sup>3</sup>See Monacelli and Perotti (2008) for a discussion of the impact of preferences on the size of the government spending multiplier in models with Calvo-style frictions when the zero bound is not binding.

by:

$$\frac{dY_t}{dG_t} = \frac{[\gamma(\sigma - 1) + 1](1 - \rho)}{1 - \rho + (1 - g)\phi_2} > 0.$$

Note that when  $\phi_2 = 0$  the multiplier is greater than one as long as  $\sigma$  is greater than one.

When prices are perfectly flexible ( $\kappa = \infty$ ) the markup is constant. In this case the multiplier is less than one:

$$\frac{dY_t}{dG_t} = \frac{1}{1 + (1 - g)\frac{N}{1 - N}} < 1.$$

This result reflects the fact that with flexible prices an increase in government spending has no impact on the markup. As a result, the demand for labor does not rise as much as in the case in which prices are sticky.

Third, the multiplier is a decreasing function of  $\phi_1$ . The intuition for this effect is that the expansion in output increases marginal cost which in turn induces a rise in inflation. According to equation (2.6) the monetary authority increases the interest rate in response to a rise in inflation. The rise in the interest rate is an increasing function of  $\phi_1$ . Higher values of  $\phi_1$  lead to higher values of the real interest rate which are associated with lower levels of consumption. So, higher values of  $\phi_1$  lead to lower values of the multiplier.

Fourth, the multiplier is a decreasing function of  $\phi_2$ . The intuition underlying this effect is similar to that associated with  $\phi_1$ . When  $\phi_2$  is large there is a substantial increase in the real interest rate in response to a rise in output. The contractionary effects of the rise in the real interest rate on consumption reduce the size of the multiplier.

Fifth, the multiplier is an increasing function of  $\rho_R$ . The intuition for this result is as follows. The higher is  $\rho_R$  the less rapidly the monetary authority increases the interest rate in response to the rise in marginal cost and inflation that occur in the wake of an increase in government purchases. This result is



consistent with the traditional view that the government-spending multiplier is greater in the presence of accommodative monetary policy. By accommodative we mean that the monetary authority raises interest rates slowly in the presence of a fiscal expansion.

Sixth, the multiplier is a decreasing function of the parameter governing the persistence of government purchases,  $\rho$ . The intuition for this result is that the present value of taxes associated with a given innovation in government purchases is an increasing function of  $\rho$ . So the negative wealth effect on consumption is an increasing function of  $\rho$ .<sup>4</sup>

Our numerical results suggest that the multiplier in a simple new-Keynesian model can be above one for reasonable parameter values. However, it is difficult to obtain multipliers above 1.2 for plausible parameter values.

### **3. The constant-interest-rate multiplier in a model without capital**

In this section we analyze the government-spending multiplier in our simple new-Keynesian model when the nominal interest rate is constant. We focus on the case in which the nominal interest rate is constant because the zero bound binds. Our basic analysis of the multiplier builds on the work of Christiano (2004) and Eggertsson (2004) and Eggertsson and Woodford (2003). As in these papers the shock that makes the zero bound binding is an increase in the discount factor. We think of this shock as representing a temporary rise in agents' propensity to save.

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<sup>4</sup>We redid our calculations using a forward-looking Taylor rule in which the interest rate responds to the one-period-ahead expected inflation and output gap. The results that we obtained are very similar to the ones discussed in the main text.

**A discount factor shock** We modify agent's preferences, given by (2.1), to allow for a stochastic discount factor,

$$U = E_0 \sum_{t=0}^{\infty} d_t \left[ \frac{[C_t^\gamma (1 - N_t)^{1-\gamma}]^{1-\sigma} - 1}{1 - \sigma} + v(G_t) \right]. \quad (3.1)$$

The cumulative discount factor,  $d_t$ , is given by:

$$d_t = \begin{cases} \frac{1}{1+r_1} \frac{1}{1+r_2} \cdots \frac{1}{1+r_t}, & t \geq 1, \\ 1 & t = 0. \end{cases} \quad (3.2)$$

The time- $t$  discount factor,  $r_t$ , can take on two values:  $r$  and  $r^l$ , where  $r^l < 0$ . The stochastic process for  $r_t$  is given by:

$$\Pr [r_{t+1} = r^l | r_t = r^l] = p, \quad \Pr [r_{t+1} = r | r_t = r^l] = 1 - p, \quad \Pr [r_{t+1} = r^l | r_t = r] = 0. \quad (3.3)$$

The value of  $r_{t+1}$  is realized at time  $t$ . We define  $\beta = 1/(1+r)$ , where  $r$  is the steady state value of  $r_{t+1}$ .

We consider the following experiment. The economy is initially in the steady state, so  $r_t = r$ . At time zero  $r_1$  takes on the value  $r^l$ . Thereafter  $r_t$  follows the process described by equation (3.3). The discount factor remains high with probability  $p$  and returns permanently to its normal value,  $r$ , with probability  $1 - p$ . In what follows we assume that  $r^l$  is sufficiently high that the zero-bound constraint on nominal interest rates binds. We assume that  $\hat{G}_t = \hat{G}^l \geq 0$  in the lower bound and  $\hat{G}_t = 0$  otherwise.

To solve the model we suppose (and then verify) that the equilibrium is characterized by two values for each variable: one value for when the zero bound binds and one value for when it is not. We denote the values of inflation and output in the zero bound by  $\pi^l$  and  $\hat{Y}^l$ , respectively. For simplicity we assume that  $\rho_R = 0$ , so there is no interest rate smoothing in the Taylor rule, (2.6). Since there are no state variables and  $\hat{G}_t = 0$  outside of the zero bound state, as soon as the zero bound is not binding the economy jumps to the steady state.

We can solve for  $\hat{Y}^l$  using equation (2.13) and the following version of equation (2.14), which takes into account the discount factor shock:

$$\begin{aligned} & \hat{Y}_t - g[\gamma(\sigma - 1) + 1]\hat{G}_t \\ = & E_t \left\{ \hat{Y}_{t+1} - g[\gamma(\sigma - 1) + 1]\hat{G}_{t+1} - \beta(1 - g)(R_{t+1} - r_{t+1}) + (1 - g)\pi_{t+1} \right\} \end{aligned} \quad (3.4)$$

We focus on the case in which the zero bound binds at time  $t$ , so  $R_{t+1} = 0$ . Equations (2.13) and (3.4) can be re-written as:

$$\hat{Y}^l = g[\gamma(\sigma - 1) + 1]\hat{G}^l + \frac{1 - g}{1 - p}(\beta r^l + p\pi^l), \quad (3.5)$$

$$\pi^l = \beta p\pi^l + \kappa \left( \frac{1}{1 - g} + \frac{N}{1 - N} \right) \hat{Y}^l - \frac{g}{1 - g} \kappa \hat{G}^l. \quad (3.6)$$

Equations (3.5) and (3.6) imply that  $\pi^l$  and  $\hat{Y}^l$  are given by:

$$\pi^l = \frac{(1 - g)\kappa \left( \frac{1}{1 - g} + \frac{N}{1 - N} \right) \beta r^l}{\Delta} + g\kappa(1 - p) \frac{\left( \frac{1}{1 - g} + \frac{N}{1 - N} \right) \gamma(\sigma - 1) + \frac{N}{1 - N}}{\Delta} \hat{G}^l. \quad (3.7)$$

$$\hat{Y}^l = \frac{(1 - \beta p)(1 - g)\beta r^l}{\Delta} + \frac{(1 - \beta p)(1 - p)[\gamma(\sigma - 1) + 1] - p\kappa}{\Delta} g \hat{G}^l, \quad (3.8)$$

where:

$$\Delta = (1 - \beta p)(1 - p) - p\kappa \left[ 1 + \frac{N}{1 - N}(1 - g) \right].$$

Since  $r^l$  is negative, a necessary condition for the zero bound to bind is that  $\Delta > 0$ . If this condition did not hold inflation would be positive and output would be above its steady state value. Consequently, the Taylor rule would call for an increase in the nominal interest rate so that the zero bound would not bind.

Equation (3.8) implies that the drop in output induced by a change in the discount rate, which we denote by  $\Theta$ , is given by:

$$\Theta = \frac{(1 - \beta p)(1 - g)\beta r^l}{\Delta}. \quad (3.9)$$

By assumption  $\Delta > 0$ , so  $\Theta < 0$ . The value of  $\Theta$  can be a large negative number for plausible parameter values. The intuition for this result is as follows. The basic shock to the economy is an increase in agent's desire to save. We develop the intuition for this result in two steps. First, we provide intuition for why the zero bound binds. We then provide the intuition for why the drop in output can be very large when the zero bound binds.

To understand why the zero bound binds, recall that in this economy saving must be zero in equilibrium. With completely flexible prices the real interest rate would simply fall to discourage agents from saving. There are two ways in which such a fall can occur: a large fall in the nominal interest rate and/or a substantial rise in the expected inflation rate. The extent to which the nominal interest rate can fall is limited by the zero bound. In our sticky-price economy a rise in the rate of inflation is associated with a rise in output and marginal cost. But a transitory increase in output is associated with a further increase in the desire to save, so that the real interest rate must rise by even more. Given the size of the shock to the discount factor, there may be no equilibrium in which the nominal interest rate is zero and inflation is positive. So the real interest rate cannot fall by enough to reduce desired saving to zero. In this scenario the zero bound binds.

Figure 1 illustrates this point using a stylized version of our model. Saving ( $S$ ) is an increasing function of the real interest rate. Since there is no investment in this economy saving must be zero in equilibrium. The initial equilibrium is represented by point  $A$ . But the increase in the discount factor can be thought of as inducing a rightward shift in the saving curve from  $S$  to  $S'$ . When this shift is large, the real interest rate cannot fall enough to re-establish equilibrium because the lower bound on the nominal interest rate becomes binding prior to reaching that point. This situation is represented by point  $B$ .

To understand why the fall in output can be very large when the zero bound

binds, recall that equation (3.7) shows how the rate of inflation,  $\pi^l$ , depends on the discount rate and on government spending in the zero bound state. In this state  $\Delta$  is positive. Since  $r^l$  is negative, it follows that  $\pi^l$  is negative and so too is expected inflation,  $p\pi^l$ . Since the nominal interest rate is zero and expected inflation is negative, the real interest rate (nominal interest rate minus expected inflation rate) is positive. Both the increase in the discount factor and the rise in the real interest rate increase agent's desire to save. There is only one force remaining to generate zero saving in equilibrium: a large, transitory fall in income. Other things equal this fall in income reduces desired saving as agents attempt to smooth the marginal utility of consumption over states of the world. Because the zero bound is a transitory state of the world this force leads to a decrease in agents desire to save. This effect has to exactly counterbalance the other two forces which are leading agents to save more. This reasoning suggest that there is a very large decline in income when the zero bound binds. In terms of Figure 1 we can think of the temporary fall in output as inducing a shift in the saving curve to the left.

We now turn to a numerical analysis of the government-spending multiplier, which is given by:

$$\frac{dY^l}{dG^l} = \frac{(1 - \beta p)(1 - p)[\gamma(\sigma - 1) + 1] - p\kappa}{\Delta}. \quad (3.10)$$

In what follows we assume that the discount factor shock is sufficiently large to make the zero bound binding. Conditional on this bound being binding, the size of the multiplier does not depend on the size of the shock. In our discussion of the standard multiplier we assume that the first-order serial correlation of government spending shocks is 0.8. To make the experiment in this section comparable we choose  $p = 0.8$ . This choice implies that the first-order serial correlation of government spending in the zero bound is also 0.8. All other parameter values

are given by the baseline specification in (2.21).

For our benchmark specification the government-spending multiplier is 3.7, which is roughly three times larger than the standard multiplier. The intuition for why the multiplier can be large when the nominal interest rate is constant, say because the zero bound binds, is as follows. A rise in government spending leads to a rise in output, marginal cost and expected inflation. With the nominal interest rate equal to zero, the rise in expected inflation drives down the real interest rate, leading to a rise in private spending. This rise in spending generates a further rise in output, marginal cost, and expected inflation and a further decline in the real interest rate. The net result is a large rise in inflation and output.

The increase in income in states where the zero bound binds raises permanent income, which raises desired expenditures in zero bound states. This additional channel reinforces the intertemporal channel stressed above. Since the zero-bound problem is temporary, we expect that the importance of this channel is relatively small.

We now consider the sensitivity of the multiplier to parameter values. The first row of Figure 2 displays the government-spending multiplier and the response of output to the discount rate shock in the absence of a change in government spending as a function of the parameter  $\kappa$ . The ‘\*’ indicates results for our benchmark value of  $\kappa$ . This row is generated assuming a discount factor shock such that  $r^l$  is equal to  $-2$  percent on an annualized basis. We graph only values of  $\kappa$  for which the zero bound binds, so we display results for  $0.02 \leq \kappa \leq 0.036$ . Three key features of this figure are worth noting. First, the multiplier can be very large. Second, absent a change in government spending, the decline in output is increasing in the degree of price flexibility, i.e. it is increasing in  $\kappa$ , as long as the zero bound binds. This result reflects that, conditional on the zero bound binding, the more flexible are prices, the higher is expected deflation and the

higher is the real interest rate. So, other things equal, higher values of  $\kappa$  require a large transitory fall in output to equate saving and investment when the zero bound binds.<sup>5</sup> Third, the government-spending multiplier is also an increasing function of  $\kappa$ .

The second row of Figure 2 displays the government-spending multiplier and the response of output to the discount rate shock in the absence of a change in government spending as a function of the parameter  $p$ . The ‘\*’ indicates results for our benchmark value of  $p$ . We graph only values of  $p$  for which the zero bound binds, so we display results for  $0.75 \leq p \leq 0.82$ . Two key results are worth noting. First, absent a change in government spending the decline in output is increasing in  $p$ . So the longer is the expected duration of the shock the worse are the output consequences of the zero bound being binding. Second, the value of the government-spending multiplier is an increasing function of  $p$ .

Figure 2 shows that the precise value of the multiplier is sensitive to the choice of parameter values. But looking across parameter values we see that the government-spending multiplier is large in economies where the drop in output associated with the zero bound is also large. Put differently, fiscal policy is particularly powerful in economies where the zero-bound state entails large output losses. One more way to see this result is to analyze the impact of changes in  $N$ , which governs the elasticity of labor supply, on  $dY^l/dG^l$  and  $\Theta$ . Equations (3.10) and (3.9) imply that:

$$\frac{dY^l}{dG^l} = \frac{(1 - \beta p)(1 - p)[\gamma(\sigma - 1) + 1] - p\kappa}{(1 - \beta p)(1 - g)\beta r^l} \Theta. \quad (3.11)$$

From equation (3.9) we see that changes in  $N$  that make  $\Delta$  converge to zero imply that  $\Theta$ , the impact of discount factor shock on output, converges to minus infinity.

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<sup>5</sup>The basic logic here is consistent with the intuition in De Long and Summers (1986) about the potentially destabilizing effects of marginal increases in price flexibility.

It follows directly from equation (3.11) that the same changes in  $N$  cause  $dY^l/dG^l$  to go to infinity. So, again we conclude that the government-spending multiplier is particularly large in economies where the output costs of being in the zero-bound state are very large.<sup>6</sup>

**Sensitivity to the timing of government spending** In practice there is likely to be a lag between the time at which the zero bound becomes binding and the time at which additional government purchases begin. A natural question is: how does the economy respond at time  $t$  to the knowledge that the government will increase spending in the future? Consider the following scenario. At time  $t$  the zero bound binds. Government spending does not change at time  $t$ , but it takes on the value  $G^l > G$  from time  $t + 1$  on, as long as the economy is in the zero bound. Under these assumptions equations (2.13) and (3.4) can be written as:

$$\pi_t = \beta p \pi^l + \kappa \left( \frac{1}{1-g} + \frac{N}{1-N} \right) \hat{Y}_t, \quad (3.12)$$

$$\hat{Y}_t = (1-g)\beta r^l + p\hat{Y}^l - g[\gamma(\sigma-1)+1]p\hat{G}^l + (1-g)p\pi^l. \quad (3.13)$$

Here we use the fact that  $\hat{G}_t = 0$ ,  $E_t(\pi_{t+1}) = p\pi^l$ ,  $E_t(\hat{G}_{t+1}) = p\hat{G}^l$ , and  $E_t(\hat{Y}_{t+1}) = p\hat{Y}^l$ . The values of  $\pi^l$  and  $\hat{Y}^l$  are given by equations (3.7) and (3.8), respectively. Using equation (3.8) to replace  $\hat{Y}^l$  in equation (3.13) we obtain:

$$\frac{dY_{t,1}}{dG^l} = \frac{1-g}{g} \frac{p}{1-p} \frac{d\pi^l}{d\hat{G}^l}. \quad (3.14)$$

Here the subscript 1 denotes the presence of a one period delay in implementing an increase in government spending. So,  $dY_{t,1}/dG^l$  represents the impact on output at time  $t$  of an increase in government spending at time  $t + 1$ . One can show that the multiplier is increasing in the probability,  $p$ , that the economy remains in

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<sup>6</sup>An exception pertains to the parameter  $\sigma$ . The value of  $dY^l/dG^l$  is monotonically increasing in  $\sigma$ , but  $d\hat{Y}^l/dr^l$  is independent of  $\sigma$ .



the zero bound. The multiplier operates through the effect of a future increase in government spending on expected inflation. If the economy is in the zero bound in the future, an increase in government purchases increases future output and therefore future inflation. From the perspective of time  $t$ , this effect leads to higher expected inflation and a lower real interest rate. This lower real interest rate reduces desired saving and increases consumption and output at time  $t$ .

Evaluating equation (3.14) at the benchmark values we obtain a multiplier equal to 1.5. While this multiplier is much lower than the benchmark multiplier of 3.7, it is still large. Moreover, this multiplier pertains to an increase in today's output in response to an increase in future government spending that only occurs if the economy is in the zero-bound state in the future.

Suppose that it takes two periods for government purchases to increase in the event that the zero bound binds. It is straightforward to show that the impact on current output of a potential increase in government spending that takes two periods to implement is given by:

$$\frac{dY_{t,2}}{dG^l} = p \frac{1-g}{g} \left[ \frac{d\pi_{t,1}}{d\hat{G}^l} + \frac{1}{1-p} \frac{d\pi^l}{d\hat{G}^l} \right].$$

Here the subscript 2 denotes the presence of a two period delay. Using our benchmark parameters the value of this multiplier is 1.44, so the rate at which the multiplier declines as we increase the implementation lag is relatively low.

Consider now the case in which the increase in government spending occurs only after the zero bound ends. Suppose, for example, that at time  $t$  the government promises to implement a persistent increase in government spending at time  $t+1$ , if the economy emerges from the zero bound at time  $t+1$ . This increase in government purchases is governed by:  $\hat{G}_{t+j} = 0.8^{j-1} \hat{G}_{t+1}$ , for  $j \geq 2$ . In this case the value of the multiplier,  $dY_t/dG_{t+1}$ , is only 0.46 for our benchmark values.

The usual objection to using fiscal policy as a tool for fighting recessions is

that there are long lags in gearing up increases in spending. Our analysis indicates that the key question is: in which state of the world does additional government spending come on line? If it comes on line in future periods when the zero bound binds there is a large effect on current output. If it comes on line in future periods where the zero bound is not binding the current effect on government spending is smaller.

**Optimal government spending** The fact that the government-spending multiplier is so large in the zero bound raises the following question: taking as given the monetary policy rule described by equation (2.6) what is the optimal level of government spending when the representative agent's discount rate is higher than its steady state level? In what follows we use the superscript  $L$  to denote the value of variables in states of the world where the discount rate is  $r^l$ . In these states of the world the zero bound may or may not be binding, depending on the level of government spending. From equation (3.7) we anticipate that the higher is government spending, the higher is expected inflation, and the less likely the zero bound is to bind.

We choose  $G^L$  to maximize the expected utility of the consumer in states of the world in which the discount factor is high and the zero bound binds. For now we assume that in other states of the world  $\hat{G}$  is zero. So, we choose  $G^L$  to maximize:

$$\begin{aligned} U^L &= \sum_{t=0}^{\infty} \left( \frac{p}{1+r^l} \right)^t \left[ \frac{[(C^L)^\gamma (1-N^L)^{1-\gamma}]^{1-\sigma} - 1}{1-\sigma} + v(G^L) \right], \quad (3.15) \\ &= \frac{1+r^r}{1+r^l-p} \left[ \frac{[(C^L)^\gamma (1-N^L)^{1-\gamma}]^{1-\sigma} - 1}{1-\sigma} + v(G^L) \right]. \end{aligned}$$

To ensure that  $U^L$  is finite we assume that  $p < (1+r^l)$ .

Note that:

$$\begin{aligned} Y^L &= N^L = Y \left( \hat{Y}^L + 1 \right), \\ C^L &= Y \left( \hat{Y}^L + 1 \right) - G \left( \hat{G}^L + 1 \right). \end{aligned}$$

Substituting these expressions into equation (3.15) we obtain:

$$\begin{aligned} U^L &= \frac{1 + r^r}{1 + r^l - p} \left[ \frac{\left( \left[ N \left( \hat{Y}^L + 1 \right) - Ng \left( \hat{G}^L + 1 \right) \right]^\gamma \left( 1 - N \left( \hat{Y}^L + 1 \right) \right)^{1-\gamma} \right)^{1-\sigma} - 1}{1 - \sigma} \right] \\ &\quad + \frac{1 + r^r}{1 + r^l - p} v \left[ Ng \left( \hat{G}^L + 1 \right) \right]. \end{aligned}$$

We choose the value of  $\hat{G}^L$  that maximizes  $U^L$  subject to the intertemporal Euler equation (equation (2.14)), the Phillips curve (equation (2.13)), and  $\hat{Y}_t = \hat{Y}^L$ ,  $\hat{G}_t = G^L$ ,  $E_t(\hat{G}_{t+1}) = pG^L$ ,  $\pi_{t+1} = \pi^L$ ,  $E_t(\pi_{t+1}) = p\pi^L$ , and  $R_{t+1} = R^L$ , where

$$R^L = \max(Z^L, 0),$$

and

$$Z^L = \frac{1}{\beta} - 1 + \frac{1}{\beta} \left( \phi_1 \pi^L + \phi_2 \hat{Y}^L \right).$$

The last constraint takes into account that the zero bound on interest rates may not be binding even though the discount rate is high.

Finally, for simplicity we assume that  $v(G)$  is given by:

$$v(G) = \psi_g \frac{G^{1-\sigma}}{1-\sigma}.$$

We choose  $\psi_g$  so that  $g = G/Y$  is equal to 0.2.

Since government purchases are financed with lump sum taxes, the optimal level of  $G$  has the property that the marginal utility of  $G$  is equal to the marginal utility of consumption:

$$\psi_g G^{-\sigma} = \gamma C^{\gamma(1-\sigma)-1} N^{(1-\gamma)(1-\sigma)}.$$

This relation implies:

$$\psi_g = \gamma ([N(1-g)])^{\gamma(1-\sigma)-1} N^{(1-\gamma)(1-\sigma)} (Ng)^\sigma.$$

Using our benchmark parameter values we obtain a value of  $\psi_g$  equal to 0.015.

Figure 3 displays the values of  $U^L$ ,  $\hat{Y}^L$ ,  $Z^L$ ,  $\hat{C}^L$ ,  $R^L$ , and  $\pi^L$  as a function of  $\hat{G}^L$ . The ‘\*’ indicates the level of a variable corresponding to the optimal value of  $\hat{G}^L$ . The ‘o’ indicates the level of a variable corresponding to the highest value of  $\hat{G}^L$  that satisfies  $Z^L \leq 0$ . A number of features of Figure 3 are worth noting. First, the optimal value of  $\hat{G}^L$  is very large: roughly 30 percent (recall that in steady state government purchases are 20 percent of output). Second, for this particular parameterization the increase in government spending more than undoes the effect of the shock which made the zero-bound constraint bind. Here, government purchases rise to the point where the zero bound is marginally non-binding and output is actually above its steady state level. These last two results depend on the parameter values that we chose and on our assumed functional form for  $v(G_t)$ . What is robust across different assumptions is that it is optimal to substantially increase government purchases and that the government-spending multiplier is large when the zero-bound constraint binds.<sup>7</sup>

**The zero bound and interest rate targeting** Up to now we have emphasized the economy being in the zero-bound state as the reason why the nominal interest rate might not change after an increase in government spending. Here we discuss

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<sup>7</sup>We derive the optimal fiscal policy taking monetary policy as given. Nakata (2009) argues that it is also optimal to raise government purchases when monetary policy is chosen optimally. He does so using a second-order Taylor approximation to the utility function in a model with separable preferences where the natural rate of interest follows an exogenous stochastic process.

an alternative interpretation of the constant interest rate assumption. Suppose that there are no shocks to the economy but that, starting from the non-stochastic steady state, government spending increases by a constant amount and the monetary authority deviates from the Taylor rule, keeping the nominal interest rate equal to its steady-state value. This policy shock persists with probability  $p$ . It is easy to show that the government-spending multiplier is given by equation (3.10). So the multiplier is exactly the same as in the case in which the nominal interest rate is constant because the zero bound binds. Of course there is no reason to think that it is sensible for the central bank to pursue a policy that sets the nominal interest rate equal to a positive constant. For this reason, a binding zero bound is the most natural interpretation for why the nominal interest rate might not change after an increase in government spending.

#### 4. A model with capital

In the previous section we use a simple model without capital to argue that the government-spending multiplier is large whenever the output costs of being in the zero-bound state are also large. Here we show that this basic result extends to a generalized version of the previous model in which we allow for capital accumulation. As above we focus on the effect of a discount-rate shock.<sup>8</sup>

**The model** The preferences of the representative household are given by equations (3.1) and (3.2). The household's budget constraint is given by:

$$P_t(C_t + I_t) + B_{t+1} = B_t(1 + R_t) + W_tN_t + P_t r_t^k K_t + T_t, \quad (4.1)$$

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<sup>8</sup>In a previous version of this paper, available upon request, we also analyse the effect of a neutral and an investment-specific technology shock.

where  $I_t$  denotes investment,  $K_t$  is the stock of capital, and  $r_t^k$  is the real rental rate of capital. The capital accumulation equation is given by:

$$K_{t+1} = I_t + (1 - \delta) K_t - D(I_t, I_{t-1}, K_t), \quad (4.2)$$

where the function  $D(I_t, I_{t-1}, K_t)$  represents investment adjustment costs. To assess robustness we consider two specifications for these adjustment costs. The first specification is the one considered in Lucas and Prescott (1971):

$$D(I_t, I_{t-1}, K_t) = \frac{\sigma_I}{2} \left( \frac{I_t}{K_t} - \delta \right)^2 K_t. \quad (4.3)$$

The parameter  $\sigma_I > 0$  governs the magnitude of adjustment costs to capital accumulation. As  $\sigma_I \rightarrow \infty$ , investment and the stock of capital become constant. The resulting model behaves in a manner very similar to the one described in the previous section.

The second specification is the one considered in Christiano, Eichenbaum and Evans (2005) and in Section 5:

$$D(I_t, I_{t-1}, K_t) = \left[ 1 - S \left( \frac{I_t}{I_{t-1}} \right) \right] I_t. \quad (4.4)$$

Here the function  $S$  is increasing, convex and satisfies the following conditions:  $S(1) = S'(1) = 0$ .

The household's problem is to maximize life-time expected utility, given by equations (3.1) and (3.2), subject to the resource constraints given by equations (4.1) and (4.2) and the condition  $E_0 \lim_{t \rightarrow \infty} B_{t+1} / [(1 + R_0)(1 + R_1) \dots (1 + R_t)] \geq 0$ .

It is useful to derive an expression for Tobin's  $q$ , i.e. the value in units of consumption of an additional unit of capital. We denote this value by  $q_t$ . For simplicity we derive this expression using the adjustment costs specification (4.3). Equation (4.3) implies that increasing investment by one unit raises  $K_{t+1}$  by

$1 - \sigma_I \left( \frac{I_t}{K_t} - \delta \right)$  units. It follows that the optimal level of investment satisfies the following equation:

$$1 = q_t \left[ 1 - \sigma_I \left( \frac{I_t}{K_t} - \delta \right) \right]. \quad (4.5)$$

**Firms** The problem of the final good producers is the same as in the previous section. The discounted profits of the  $i^{th}$  intermediate good firm are given by:

$$E_t \sum_{j=0}^{\infty} \beta^{t+j} v_{t+j} \left\{ P_{t+j}(i) Y_{t+j}(i) - (1 - \nu) [W_{t+j} N_{t+j}(i) + P_{t+j} r_{t+j}^k K_{t+j}(i)] \right\}. \quad (4.6)$$

Output of good  $i$  is given by:

$$Y_t(i) = [K_t(i)]^\alpha [N_t(i)]^{1-\alpha},$$

where  $N_t(i)$  and  $K_t(i)$  denote the labor and capital employed by the  $i^{th}$  monopolist.

The monopolist is subject to the same Calvo-style price-setting frictions described in Section 2. Recall that  $\nu = 1/\varepsilon$  denotes a subsidy that is proportional to the costs of production. This subsidy corrects the steady-state inefficiency created by the presence of monopoly power. The variable  $v_{t+j}$  is the multiplier on the household budget constraint in the Lagrangian representation of the household problem. Firm  $i$  maximizes its discounted profits, given by equation (4.6), subject to the Calvo price-setting friction, the production function, and the demand function for  $Y_t(i)$ , given by equation (2.4).

The monetary policy rule is given by equation (2.6).

**Equilibrium** The economy's resource constraint is:

$$C_t + I_t + G_t = Y_t. \quad (4.7)$$

A ‘monetary equilibrium’ is a collection of stochastic processes,

$$\{C_t, I_t, N_t, K_t, W_t, P_t, Y_t, R_t, P_t(i), r_t^k, Y_t(i), N_t(i), v_t, B_{t+1}, \pi_t\},$$

such that for given  $\{d_t, G_t\}$ , the household and firm problems are satisfied, the monetary policy rule given by equation (2.6) is satisfied, markets clear, and the aggregate resource constraint holds.

**Experiment** At time zero the economy is in its non-stochastic steady state. At time one agents learn that  $r^L$  differs from its steady state value for  $T$  periods and then returns to its steady state value. We consider a shock that is sufficiently large so that the zero bound on the nominal interest rate binds between two time periods that we denote by  $t_1$  and  $t_2$ , where  $1 \leq t_1 \leq t_2 \leq T$ .<sup>9</sup> We solve the model using a shooting algorithm. In practice the key determinants of the multiplier are  $t_1$  and  $t_2$ . To maintain comparability with the previous section we keep the size of the discount factor shock the same and choose  $T = 10$ . In this case  $t_1$  equals one and  $t_2$  equals six. Consequently, the length for which the zero bound binds after a discount rate shock is roughly the same as in the model without capital.

With the exception of  $\sigma_I$  and  $\delta$  all parameters are the same as in the economy without capital. We set  $\delta$  equal to 0.02. We choose the value of  $\sigma_I$  so that the elasticity of  $I/K$  with respect to  $q$  is equal to the value implied by the estimates in Eberly, Rebelo, and Vincent (2008).<sup>10</sup> The resulting value of  $\sigma_I$  is equal to 17.

We compute the government spending multiplier under the assumption that  $G_t$  increases by  $\hat{G}$  percent for as long as the zero bound binds. In general, the increase in  $G_t$  affects the time period over which the zero bound binds. Consequently we

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<sup>9</sup>The precise timing of when the zero-bound constraint is binding may not be unique.

<sup>10</sup>Eberly, Rebelo and Vincent (2008) obtain a point estimate of  $b$  equal to 0.06 in the regression  $I/K = a + b \ln(q)$ . This estimate implies a steady state elasticity of  $I_t/K_t$  with respect to Tobin’s  $q$  of  $0.06/\delta$ . Our theoretical model implies that this elasticity is equal to  $(\sigma_I \delta)^{-1}$ . Equating these two elasticities yields a value of  $\sigma_I$  of 17.



proceed as follows. Guess a value for  $t_1$  and  $t_2$ . Increase  $G_t$  for the period  $t \in [t_1, t_2]$ . Check that the zero bound binds for  $t \in [t_1, t_2]$ . If not revise the guess for  $t_1$  and  $t_2$ .

Denote by  $\hat{Y}_t$  the percentage deviation of output from steady state that results from a shock that puts the economy into the zero-bound state holding  $G_t$  constant. Let  $\hat{Y}_t^*$  denote the percentage deviation of output from steady state that results from the both the original shock and the increase in government purchases described above. We compute the government spending multiplier as follows:

$$\frac{dY_t}{dG_t} = \frac{1}{g} \frac{\hat{Y}_t^* - \hat{Y}_t}{\hat{G}}.$$

As a reference point we note that when the zero bound is not binding the government-spending multiplier is roughly 0.9. This value is lower than the value of the multiplier in the model without capital. This lower value reflects the fact that an increase in government spending tends to increase real interest rates and crowd out private investment. This effect is not present in the model without capital.

We now consider the effect of an increase in the discount factor from its steady state value of four percent (APR) to  $-1$  percent (APR). The solid line in Figure 4 displays the dynamic response of the economy to this shock. The zero bound binds in periods one through six. The higher discount rate leads to substantial declines in investment, hours worked, output, and consumption. The large fall in output is associated with a fall in marginal cost and substantial deflation. Since the nominal interest rate is zero, the real interest rate rises sharply. We now discuss the intuition for how the presence of investment affects the response of the economy to a discount rate shock. We begin by analyzing why a rise in the real interest rate is associated with a sharp decline in investment. Ignoring covariance

terms, the household's first-order condition for investment can be written as:

$$E_t \left( \frac{1 + R_{t+1}}{P_{t+1}/P_t} \right) = \frac{1}{q_t} E_t \alpha K_{t+1}^{\alpha-1} N_{t+1}^{1-\alpha} s_{t+1} + \quad (4.8)$$

$$\frac{1}{q_t} E_t \left\{ q_{t+1} \left[ (1 - \delta) - \frac{\sigma_I}{2} \left( \frac{I_{t+1}}{K_{t+1}} - \delta \right)^2 + \sigma_I \left( \frac{I_{t+1}}{K_{t+1}} - \delta \right) \frac{I_{t+1}}{K_{t+1}} \right] \right\},$$

where  $s_t$  is the inverse of the markup rate. Equation (4.8) implies that in equilibrium the household equates the returns to two different ways of investing one unit of consumption. The first strategy is to invest in a bond that yields the real interest rate defined by the left-hand side of equation (4.8). The second strategy involves converting the consumption good into  $1/q_t$  units of installed capital. The return to this capital has three components. The first component is the marginal product of capital (the first term on the right-hand side of equation (4.8)). The second component is the value of the undepreciated capital in consumption units,  $q_{t+1}(1 - \delta)$ . The third component is the value in consumption units of the reduction in adjustment costs associated with an increase in installed capital.

To provide intuition it is useful to consider two extreme cases, infinite adjustment costs ( $\sigma_I = \infty$ ) and zero adjustment costs ( $\sigma_I = 0$ ). Suppose first that adjustment costs are infinite. Figure 1 displays a stylized version of this economy. Investment is fixed and saving is an increasing function of the real interest rate. The increase in the discount factor can be thought of as inducing a rightward shift in the saving curve. When this shift is very large, the real interest rate cannot fall enough to re-establish equilibrium. The intuition for this result and the role played by the zero bound on nominal interest rates is the same as in the model without capital. That model also provides intuition for why the equilibrium is characterized by a large, temporary fall in output, deflation, and a rise in the real interest rate.

Suppose now that there are no adjustment costs ( $\sigma_I = 0$ ). In this case Tobin's

$q$  is equal to  $e^{-\psi}$  and equation (4.8) simplifies to:

$$E_t \frac{1 + R_{t+1}}{P_{t+1}/P_t} = E_t [\alpha K_{t+1}^{\alpha-1} N_{t+1}^{1-\alpha} s_{t+1} + (1 - \delta)].$$

According to this equation an increase in the real interest rate must be matched by an increase in the marginal product of capital. In general the latter is accomplished, at least in part, by a fall in  $K_{t+1}$  caused by a large drop in investment. In Figure 1 the downward sloping curve labeled ‘elastic investment’ depicts the negative relation between the real interest rate and investment in the absence of any adjustment costs. As drawn, the shift in the saving curve moves the equilibrium to point  $C$  and does not cause the zero bound to bind. So, the result of an increase in the discount rate is a fall in the real interest rate and a rise in saving and investment.

Now consider a value of  $\sigma_I$  that is between zero and infinity. In this case both investment and  $q$  respond to the shift in the discount factor. For our parameter values, the higher the adjustment costs the more likely it is that the zero bound binds. In terms of Figure 1 a higher value of  $\sigma_I$  can be thought of as generating a steeper slope in the investment curve, thus increasing the likelihood that the zero bound binds.

Suppose that the zero bound binds. Other things equal, a higher real interest rate increases desired saving and decreases desired investment. So the fall in output required to equate the two must be larger than in an economy without investment. This larger fall in output is undone by an increase in government purchases.<sup>11</sup> Consistent with this intuition Figure 4 shows that the government-spending multiplier is very large when the zero bound binds (on impact  $dY/dG$  is roughly equal to four). This multiplier is actually larger than in the model

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<sup>11</sup>As in the model without capital the increase in income in states where the zero bound binds raises permanent income which raises desired expenditures in zero bound states. This additional channel reinforces the intertemporal channel stressed in the text.

without capital.<sup>12</sup>

A natural question is what happens to the size of the multiplier as we increase the size of the shock. Recall that in the model without capital, as long as the zero bound binds, the size of the shock does not affect the size of the multiplier. The analogue result here, established using numerical methods, is that the size of the shock does not affect the multiplier as long as it does not affect  $t_1$  and  $t_2$ . For a given  $t_1$  the size of the multiplier is decreasing in  $t_2$ . For example, suppose that shock is such that  $t_2$  is equal to four instead of the benchmark value of six. In this case the value of the multiplier falls from 3.9 to 2.3. The latter value is still much larger than 0.9, the value of the multiplier when the zero bound does not bind.

We conclude by considering the effect of using the adjustment-cost specification given by equation (4.4) rather than equation (4.3). The dashed line in Figure 4 displays the dynamic response of the economy to the discount rate shock. Four key results emerge. First, the response of investment is smaller with the new adjustment cost specification which directly penalizes changes in investment. Second, while large the multiplier (2.6 on impact) is somewhat smaller with the new investment cost specification. This result reflects the smaller response of investment. Third, the dynamic responses of the other variables are similar across the two adjustment cost specifications. Fourth, the values of  $t_1$  and  $t_2$ , indicating the period of time over which the zero bound binds are the same. We conclude that the main results regarding the zero bound are robust across the two.

## 5. The multiplier in a medium-size DSGE model

In the previous sections we built intuition about the size of the government-spending multiplier using a series of simple new-Keynesian models. In this section

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<sup>12</sup>This multiplier is computed setting  $\hat{G}$  to one percent.

we investigate the determinants of the multiplier in the version of ACEL in which capital is firm specific. The model includes a variety of frictions that are useful for explaining aggregate time-series data. These frictions include sticky wages, sticky prices, variable capital utilization, and the CEE investment adjustment-cost specification. In what follows all notation is the same as in the previous sections, unless noted otherwise.

The final good is produced using a continuum of intermediate goods according to the production function and market structure described in Section 2. Intermediate good  $i \in (0, 1)$  is produced by a monopolist using the technology:

$$y_t(i) = \max [\bar{K}_t(i)^\alpha N_t(i)^{1-\alpha} - \phi, 0], \quad (5.1)$$

where  $0 < \alpha < 1$ . Here,  $N_t(i)$  and  $\bar{K}_t(i)$  denote time  $t$  labor and capital services used to produce the  $i^{\text{th}}$  intermediate good. The parameter  $\phi$ , represents a fixed cost of production. The services of capital,  $\bar{K}_t(i)$ , are related to stock of physical capital,  $K_t(i)$ , by

$$\bar{K}_t(i) = u_t(i)K_t(i).$$

Here  $u_t(i)$  is the utilization rate. The cost in investment goods of setting the utilization rate to  $u_t(i)$  is given by  $a(u_t(i))K_t(i)$ , where  $a(u_t)$  is increasing and convex. We define  $\sigma_a = a''(1)/a'(1) \geq 0$  and impose that  $u_t = 1$  and  $a(1) = 0$  in steady state.

Intermediate-good firms own their capital, which they cannot adjust within the period. They can only change their stock of capital over time by varying the rate of investment. A firm's stock of physical capital evolves according to equations (4.2) and (4.4).

Intermediate good firms purchase labor services in a perfectly competitive labor market at the wage rate  $W_t$ . Firms must borrow the wage bill in advance from financial intermediaries at the gross interest rate,  $R_t$ . Profits are distributed

to households at the end of each time period.

With one modification, intermediate-good firms set their price subject to the Calvo (1983) frictions described in Section 2. The modification is that a firm which cannot re-optimize its price sets  $P_t(i)$  according to:  $P_t(i) = \pi_{t-1}P_{t-1}(i)$ . The  $i^{\text{th}}$  intermediate good firm's objective function is given by:

$$E_t \sum_{j=0}^{\infty} \beta^{t+j} v_{t+j} \{ P_{t+j}(i) Y_{t+j}(i) - W_{t+j} R_{t+j} N_{t+j}(i) - [P_{t+j} I_{t+j}(i) + P_{t+j} a(u_{t+j}(i)) K(i)_{t+j}] \} \quad (5.2)$$

There is a continuum of households indexed by  $j \in (0, 1)$ . Each household is a monopoly supplier of a differentiated labor service, and sets its wage subject to Calvo-style wage frictions as in Erceg, Henderson, and Levin (2000). Household  $j$  sells its labor at a wage rate  $W_{j,t}$  to a representative competitive firm that transforms it into an aggregate labor input,  $N_t$ , using the technology:

$$N_t = \left[ \int_0^1 N_{j,t}^{\frac{1}{\lambda_w}} dj \right]^{\lambda_w}, \quad 1 \leq \lambda_w < \infty.$$

This firm sells the composite labor service to intermediate good firms at a price  $W_t$ .

We assume that there exist complete contingent claims markets. So, in equilibrium all household consume the same amount and have the same asset holdings. Our notation reflects this result. The preferences of the  $j^{\text{th}}$  household are given by:

$$E_t^j \sum_{s=0}^{\infty} \beta^s \left[ \log(C_{t+s} - bC_{t+s-1}) - \frac{N_{j,t+s}^2}{2} \right], \quad (5.3)$$

where  $E_t^j$  is the time  $t$  expectation operator, conditional on household  $j$ 's time  $t$  information set. The parameter  $b > 0$  governs the degree of habit formation in

consumption. The household's budget constraint is:

$$M_{t+1} = R_t [M_t - Q_t + (x_t - 1)M_t^a] + A_{j,t} + Q_t + W_{j,t}N_{j,t} + D_t - (1 + \eta(\mathcal{V}_t)) P_t C_t - T_t. \quad (5.4)$$

Here  $M_t$ ,  $Q_t$  and  $W_{j,t}$  denote the household's stock of money at the beginning of period  $t$ , cash balances and time  $t$  nominal wage rate, respectively. Also,  $T_t$  denotes period- $t$  lump-sum taxes. Each household has a diversified portfolio of claims on all the intermediate good firms. The variable  $D_t$  represents period  $t$  firm profits. The variable  $A_{i,t}$ , denotes the net cash inflow from participating in state-contingent securities at time  $t$ . The variable  $x_t$ , represents the gross growth rate of the economy-wide per capita stock of money,  $M_t^a$ . The quantity  $(x_t - 1)M_t^a$  is a lump-sum payment made to households by the monetary authority. The household deposits  $M_t - Q_t + (x_t - 1)M_t^a$  with a financial intermediary. The variable  $\mathcal{V}_t$ , denotes the time  $t$  velocity of the household's cash balances:  $\mathcal{V}_t = (P_t C_t) / Q_t$ . The function  $\eta(\mathcal{V}_t)$  captures the role of cash balances in facilitating transactions. This function is increasing and convex. The first-order condition for  $Q_t$  implies that the interest semi-elasticity of money demand in steady state is:

$$\epsilon = \frac{1}{4} \left( \frac{1}{R - 1} \right) \left( \frac{1}{2 + \eta'' \mathcal{V} / \eta'} \right),$$

We parameterize  $\eta(\cdot)$  indirectly by choosing steady state values for  $\epsilon$ ,  $\mathcal{V}$  and  $\eta$ .

Financial intermediaries receive  $M_t - Q_t + (x_t - 1) M_t$  from the household. Our notation reflects the equilibrium condition,  $M_t^a = M_t$ . Financial intermediaries lend all of their money to intermediate good firms, which use the funds to pay the wage bill. Loan market clearing requires that:

$$W_t H_t = x_t M_t - Q_t. \quad (5.5)$$

The aggregate resource constraint is:

$$[1 + \eta(\mathcal{V}_t)] C_t + [I_t + a(u_t) K_t] = Y_t. \quad (5.6)$$

The monetary policy rule is given by equation (2.6).

**Assigning values to model parameters** In our analysis, we assume that the financial crisis began in the third quarter of 2008. For our experiments we require that the level of the interest rate in the model coincides with that in the data in the second quarter of 2008. A simple way to do this is to suppose that the model is in steady state in the second quarter of 2008 with a nominal interest rate of 2 percent. To this end, we set  $\beta = 0.9999$  and  $x = 1.0049$ .

We assume that intermediate-good firms set their prices once a year ( $\xi_P = 0.75$ ). In conjunction with the other model parameters, the firm-specific capital version of ACEL implies that the coefficient on marginal cost in the new-Keynesian Phillips curve is 0.0026. The low value of this coefficient is consistent with the evidence presented in Figure 4 of ACEL. We set  $\xi_W$  equal to 0.72, the point estimate in ACEL, so that households reoptimize wages roughly once a year. We set the habit formation parameter  $b$  to 0.70, a value similar to the point estimates in ACEL and CEE. The quarterly rate of depreciation rate,  $\delta$ , is 0.02. We set the parameter  $\alpha$  to 0.3. In conjunction with the other parameter values, this value of  $\alpha$  generates a steady-state value of  $I_t/(C_t + I_t + G_t)$  equal to 0.29, the average value of this ratio in U.S. data over the period from 1960Q1 to 2010Q1. The precise measures of these variables are discussed below.

We set  $S''(1)$ ,  $\varepsilon$ , and  $\sigma_a$  to the values estimated in ACEL (3.28, 0.80, and 2.02, respectively). We set the parameter  $\phi$  to ensure that the steady-state profits of intermediate-goods firms are zero. We set the steady-state values of  $V$ ,  $\eta$ ,  $\lambda_f$  and  $\lambda_w$  to the values used in ACEL (0.45, 0.036, 1.01, and 1.05, respectively). We find that our results are robust to perturbations in this last set of parameters. Finally, we assume that monetary policy is conducted according to the Taylor rule described in equation (2.6) with  $\phi_1 = 0.25$ ,  $\phi_2 = 1.5$ , and  $\rho = 0$ .



**The multiplier in ACEL** Figure 5 reports the value of the multiplier implied by the model under different scenarios. The first row of Figure 5 shows that the value of the government-spending multiplier when monetary policy is governed by a Taylor rule and the zero bound is not binding. We consider the case where government spending increases by a constant amount for eight and twelve quarters, respectively. The key result here is that during the first eight quarters in which the experiments are comparable the multiplier is higher in the first case than in the second case. This result is consistent with the analysis in Section 2 which argues that, when the Taylor rule is operative, the magnitude of the multiplier is decreasing in the persistence of the shock to government spending.

The first row of Figure 5 also shows the value of the government spending multiplier when an increase in government spending coincides with a nominal interest rate that is constant, say because the zero bound binds.<sup>13</sup> Interestingly, when government spending rises for only eight quarters, the government-spending multiplier is roughly 1.2. When the Taylor rule is operative the multiplier is smaller. It starts at roughly one and declines to about 0.7. When government spending rises for twelve quarters there is a much larger difference between the Taylor rule case and the zero-bound case. In the latter case the impact multiplier is roughly 1.6. The multiplier rises in a hump-shaped manner, attaining a peak value of roughly 2.3 after five periods. The hump-shaped response of the multiplier reflects the endogenous sources of persistence present in ACEL, e.g. habit formation in consumption and investment adjustment costs. The zero-bound multiplier is substantially larger when the zero bound binds for twelve periods rather than for eight periods. This result is consistent with a central finding of this paper: the government spending multiplier is larger the more severe is the zero-bound

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<sup>13</sup>Recall that the value of the multiplier does not depend on why the nominal interest rate is constant. Given this property, we study the size of the multiplier in ACEL without specifying either the type or the magnitude of the shock that makes the zero bound binding.

problem.<sup>14</sup>

The second row of Figure 5 provides information to address the following question: how sensitive is the multiplier to the proportion of government spending that occurs while the nominal interest rate is zero? The figure displays the government-spending multipliers when government spending goes up for 12, 16, and 24 periods. In all cases the nominal interest rate is zero for 12 periods and follows a Taylor rule thereafter. So, in the three cases the proportion of government spending that comes online while the nominal interest rate is zero is 100, 75, and 50 percent, respectively.

Our basic result is that the multipliers are higher the larger is the percentage of the spending that comes online when the nominal interest rate is zero. This result holds even in the first 12 periods when the increase in government spending is the same in all three cases. For example, the peak multiplier falls from roughly 2.3 to 1.06 as we go from the first to the third case. This decline is consistent with our discussion of the sensitivity of the multiplier to the timing of government spending in Section 3. A key lesson from this analysis is that if fiscal policy is to be used to combat a shock that sends the economy into the zero bound, it is critical that the spending come on line when the economy is actually in the zero bound. Spending that occurs after that yields very little bang for the buck and actually dulls the impact of the spending that comes on line when the zero bound binds.

Using a model similar to ACEL, Cogan, Cwik, Taylor, and Wieland (2010) study the impact of increases in government spending when the nominal interest rate is set to zero for one or two years. A common feature of their experiments is that the bulk of the increase in government spending comes on line when the

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<sup>14</sup>For completeness we also considered the case in which the zero bound binds for only four quarters. In this case the zero-bound multiplier and the multiplier when the Taylor rule is operative are very similar.

nominal interest rate is no longer constant. Consistent with our results, Cogan et al. (2010) find modest values for the government-spending multiplier.

**The model’s performance during the crisis period** The ACEL model and close variants of it do a good job at accounting for the key properties of U.S. time series data in the period before the financial crisis (see, for example, ACEL and Smets and Wouters (2007)). One natural question is whether the model generates sensible predictions for the current crisis under the assumption that the zero bound binds.

The solid lines in Figure 6 display time-series data for the period 2000Q1-2010Q1 for real per capita output, private consumption, investment, government consumption, inflation, and the Federal Funds rate. The data displayed are the percentage change in a variable from its value in 2000Q1. All per capita variables are computed using as a measure of the population the civilian noninstitutional population, 16 years and over. All variables with the exception of inflation and the interest rate are seasonally adjusted and computed as real chained-weighted billions of 2005 U.S. dollars.<sup>15</sup> Output is the sum of consumption, investment and government consumption.<sup>16</sup> We also discuss results when we use real GDP

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<sup>15</sup>To aggregate real chain-weighted data we proceed as follows. Denote two nominal quantities by  $\tilde{x}_{1t}$  and  $\tilde{x}_{2t}$  and the two associated price indices by  $p_{1t}$  and  $p_{2t}$ . The real quantities are given by:  $x_{it} = \tilde{x}_{it}/p_{it}$ ,  $i = 1, 2$ . The growth rate of the price of the aggregate,  $\pi_t$ , is the geometric average of the Laspeyres and Paasche indices:  $\pi_t = \sqrt{\left(\frac{p_{1t}x_{1t-1} + p_{2t}x_{2t-1}}{p_{1t-1}x_{1t-1} + p_{2t-1}x_{2t-1}}\right) \left(\frac{p_{1t}x_{1t} + p_{2t}x_{2t}}{p_{1t-1}x_{1t} + p_{2t-1}x_{2t}}\right)}$ , for  $t > 1$ . We obtain a time series on the price of  $x_t$ ,  $p_t$ , by setting this price in some initial condition and solving:  $p_t = \pi_t p_{t-1}$ ,  $p_0 = 1$ , for  $t = 1, \dots, T$ . The real quantity of the aggregate is:  $\tilde{x}_t = (\tilde{x}_{1t} + \tilde{x}_{2t})/p_t$ ,  $t = 0, \dots, T$ .

<sup>16</sup>If we construct output using the procedure for chain-weighting discussed above, the equation  $Y_t = C_t + I_t + G_t$  does not hold. Since this equation holds in the model we report an empirical measure of output for which this equation also holds. This measure is a weighted average of chain-weighted  $C_t$ ,  $I_t$ , and  $G_t$  where the weights are 56, 29 and 15 percent, respectively. These weights are the sample averages of the nominal shares of the three series. Since we report the model’s implications for  $C_t$ ,  $I_t$ , and  $G_t$  separately, the reader can assess the model’s implications for the individual components of our measure of output.

as the measure of output. Private consumption is consumption of nondurables and services. Investment is household purchases of durable goods, federal government investment, and gross private domestic investment. Total government consumption is federal government consumption and state and local expenditures on consumption and investment.<sup>17</sup> Inflation is the year over year growth rate in the core consumer price index. The interest rate is the Federal Funds rate.

We date the beginning of the financial crisis as the third quarter of 2008. This is the quarter during which Lehman Brothers collapsed. We are interested in computing the effect of the financial crisis on the evolution of the U.S. economy. To this end we forecast the variables reported in Figure 6 using data up to and including the second quarter of 2008. With the exception of output, inflation and the interest rate we compute our forecasts using a four lag scalar autoregression fit to the level of the data. The output forecast is equal to the weighted sum of the forecasted values of consumption, investment, and government purchases. The forecasts for the interest rate and inflation are equal to the level of these variables in 2008Q2. These forecasts are displayed as the dotted lines in Figure 6.

A rough measure of the impact of the crisis on the variables included in Figure 6 is the difference between the actual and the forecasted values of these variables. These differences, i.e. the impulse response functions to the shocks that precipitated the crisis, are displayed as the solid lines in Figure 7. It is evident that the nominal interest rate fell very quickly and hit the zero bound. There was a significant drop in consumption and a very large fall in investment. Output fell by seven percent. Inflation fell by one percent relative to what it would be absent the crisis. Despite the fiscal stimulus plan enacted in February 2009 (the American Recovery and Reinvestment Act), total government consumption rose by only

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<sup>17</sup>We include state and local government consumption and investment in our measure of government consumption because data on real state and local government investment is not available for the period before 1995.

two percent. Total government purchases, which includes both consumption and investment, rose by even less. This result reflects two facts. First, a substantial part of the stimulus plan involved an increase in transfers to households. Second, there was a large fall in state and local purchases that offset a substantial part of the increase in federal government purchases.<sup>18</sup>

To assess the model’s implication for the crisis period we need to specify the shocks that made the zero bound binding. In our view the crisis was precipitated by disturbances in financial markets that increased the spread between the return on savings and the return on investment. The financial crisis and the resulting uncertainty led to a large rise in the household’s desire to save. Consistent with this view the personal savings rate rose sharply from roughly two percent in 2007 to a level that stabilized at around 5.5 percent.<sup>19</sup> The ACEL model is not sufficiently rich to provide a detailed account of the financial crisis or the steep rise in household saving. We mimic the effects of the crisis by introducing the discount factor shock discussed in the previous sections, as well as a financial friction shock.

The ACEL model assumes that firms finance investment out of retained earnings. We imagine that each dollar passing between households and firms goes through the financial system. In normal times every dollar transferred between households and firms uses up  $\tau$  dollars’ worth of final goods. Thus, we replace  $v_{t+j}$  in (5.2) with  $v_{t+j}(1 - \tau)$ . Abstracting from general equilibrium effects on  $v_{t+j}$  in (5.2), the value of  $\tau$  does not affect the firm’s decisions, as long as it is constant.<sup>20</sup> We assume that  $\tau$  is constant until 2008Q2 and that agents expected it to remain

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<sup>18</sup>See Cogan and Taylor (2010) for a detailed analysis of the impact of the American Recovery and Reinvestment Act on government spending.

<sup>19</sup>These observations are based on the saving rate, PSAVERT, obtained from the Federal Reserve Bank of St. Louis website.

<sup>20</sup>The general equilibrium effect operates through the impact of  $\tau$  on the aggregate resource constraint. In our computations, we abstract from this general equilibrium effect on the grounds that it is presumably small.

constant forever. At the onset of the financial crisis in 2008Q3, agents learn that the costs of intermediation rise. Let

$$1 - \tau^k \equiv \frac{1 - \tau_t}{1 - \tau_{t-1}}. \quad (5.7)$$

We suppose that  $\tau^k > 0$  for  $t$  corresponding to the first period of the crisis (i.e., 2008Q3) until the last period,  $t = T$ , of the crisis. We suppose that  $\tau_t^k = 0$  for  $t > T$ .<sup>21</sup>

The  $i^{\text{th}}$  intermediate good firm maximizes the modified version of (5.2) that accommodates  $\tau_t^k$ . The necessary first-order condition for investment can be written as follows:

$$u_{ct} = E_t \beta u_{ct+1} R_{t+1}^k(i) (1 - \tau_{t+1}^k). \quad (5.8)$$

Here,  $u_{ct}$ , which is taken as given by the firm, is the marginal utility of household consumption:

$$u_{ct} = \frac{1}{C_t - bC_{t-1}} + E_t \left( \frac{\beta b}{C_{t+1} - bC_t} \right).$$

Let  $R_{t+1}^k$  denote the cross-section average return on capital, i.e. the average across  $i$  of  $R_{t+1}^k(i)$ . One measure of the interest rate spread in the model is the difference between  $R_{t+1}^k$  and the corresponding average return received by households,  $R_{t+1}^k (1 - \tau_{t+1}^k)$ . This difference is equal to  $\tau_{t+1}^k R_{t+1}^k$ .

Our assumption that  $\tau_t^k$  rose during the crisis is essentially equivalent to the assumption that our measure of the interest rate spread rose. In reality, interest rate spreads move for many reasons, e.g., changes in bankruptcy risk, changes in liquidity and confidence in the banking system. In the wake of the 2008 financial crisis, virtually all interest rate spreads rose dramatically. Consider, for example, the behavior of the interest spreads on non-AAA corporate bonds relative to AAA bonds. In the case of BAA, BB, B and ‘junk’, defined as CCC and lower

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<sup>21</sup>With this formulation, the constant, post-crisis level of  $\tau$  is higher than the pre-crisis level of  $\tau$ .

rated bonds, the average value of the spread is 0.88, 1.75, 2.71 and 5.75 percent, respectively, over the period, 2005-2007. These spreads rose to peak values of 3.38, 8.83, 14.10, and 27.72 at the end of 2008.<sup>22</sup> Thereafter, spreads declined to values of 1.20, 2.36, 3.87, and 7.88, respectively, by 2010Q3.<sup>23</sup>

With these data as background, we set  $\tau^k = 3.6/400$  and  $T = 12$ . This assumption implies that at the time of the crisis, the interest rate spread on a three year bond jumps by 3.6 percentage points at an annual rate and then declines linearly back to zero after three years.<sup>24</sup> We focus on the three year bond because the work of Barclay and Smith (1995) and Stohs and Mauer (1996) suggests that the average duration of corporate debt is in the range of three to four years.<sup>25</sup>

We assume that  $G_t$  increases by two percent for as long as the zero bound binds. As in Section 4 we compute the time interval  $t \in [t_1, t_2]$  during which the zero bound binds. We find that  $t_1 = 2$  and  $t_2 = 11$ , so the zero binds from the fourth quarter of 2008 until the third quarter of 2011.

The dash-dotted line in Figure 7 corresponds to the model's predictions for the economy during the crisis. A number of features are worth noting. First, the model accounts for the rapid decline of the federal funds rate at the onset of the crisis. Second, the model is consistent with the observed declines in consumption, investment and output. Third, and perhaps most importantly, the model also does

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<sup>22</sup>The analysis is based on quarterly averaged data. The peak of the BB and B bond spreads occurs in 2008Q4 and the peak in the junk bond spreads occurs in 2009Q1.

<sup>23</sup>All rates are in annual, percent terms.

<sup>24</sup>At time  $t$ , we calculate the interest rate spread on a three-year bond by taking the three year forward averages of quarterly interest rate spreads.

<sup>25</sup>See Stohs and Mauer (1996, Table 2). Barclay and Smith do not directly report average durations. Instead, they report the percent of debt that matures in more than  $n$  years, for  $n = 1, 2, 3, 4, 5$ . These percentages are 73, 65.7, 58.7, 52.2, 45.9 respectively. These numbers imply an average duration if one makes an assumption about the mean duration for firms with  $n > 5$ . For example, if this mean duration is 7.5, then mean duration is 4.2 years, where  $4.2 = 1.5 \times 0.073 + 2.5 \times 0.070 + 3.5 \times 0.065 + 4.5 \times 0.063 + 7.5 \times 0.459$ .

a good job of accounting for the post-crisis behavior of inflation. According to our estimates inflation fell by roughly one percent as a result of the crisis (see the solid line in Figure 7). The model's predictions are consistent with this decline.

To assess robustness with respect to our output measure Figure 7 reports the difference between the log level and the univariate forecast of per capita real GDP. This difference is displayed as the dashed line in the subplot labeled 'Output'. Notice that the paths of the two real output measures are very similar. Interestingly, our measure of output falls by somewhat more than per capita real GDP. For example, the maximal impact of the crisis is seven percent and 5.8 percent decline in our measure of output and real GDP, respectively. If we calibrate the model to match the fall in real GDP we would generate less deflation and smaller declines in consumption and investment.

We conclude by noting that, consistent with the data, in our simulations government purchases rise by only two percent for 11 periods. Recall from Figure 5 that the peak value of the multiplier in ACEL is 2.3. So the rise in government purchases accounts for, at most, a 0.7 of one percent rise in annual GDP.<sup>26</sup> The modest contribution of government purchases to the recovery reflects the very modest increase in government spending, rather than a small multiplier.

## 6. The Multiplier with Distortionary Taxation

In this section we consider how the presence of distortionary taxation affects the government spending multiplier when the zero bound binds. Baxter and King (1993) show that the size of the government spending multiplier implied by the neoclassical growth model is sensitive to the requirement that spending be financed with distortionary taxes. For example, when they require that government spend-

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<sup>26</sup>We base this calculation on the fact that  $dY/Y = (dY/dG)(dG/G)(G/Y)$  and the assumption that  $G/Y = 0.15$ .



ing be financed on a period-by-period basis with distortionary taxes on income, the multiplier actually becomes negative. This result reflects that increases in distortionary taxes reduce output in the neoclassical growth model.

A natural question is: how sensitive are our conclusions to the presence of distortionary taxes? Eggertsson (2010, 2011) shows that the effects of distortionary taxes can be very different depending on whether the zero lower bound binds or not. Indeed, some distortionary taxes that lower output when the zero lower bound does not bind actually raise output when the zero bound does bind. Of course, if the tax that finances government spending actually increases output then the government spending multiplier is actually increased.

For example, Eggertsson (2010, 2011) shows that increasing labor income taxes when the zero bound binds leads to a rise in output. The intuition for this result is as follows. Suppose that prices are sticky but wages are fully flexible. Other things equal, an increase in the labor income tax rate,  $\tau_t^L$ , is equivalent to a reduction in the supply of labor. The resulting rise in the real wage rate leads to a rise in marginal cost and a rise in inflation. As long as the zero bound binds, a rise in inflation leads to a fall in the real interest rate and a rise in consumption and output. The rise in output generates a further rise in inflation, a further decline in the real interest rate and an additional rise in output. So, the net effect of an increase in  $\tau_t^L$  while the zero bound binds is potentially a large rise in output and tax revenues. So here an increase in government spending has a bigger impact on output if it is financed by a rise in labor income taxes rather than lump-sum taxes.

Now, suppose that both prices and wages are sticky as in ACEL. Christiano (2011) argues that the quantitative effects associated with an increase in distortionary taxes is still positive but smaller than when wages are flexible. The basic reason is that, with Calvo-style sticky wages, employment is demand determined.

Consequently, labor supply effects are less important as they only directly effect the workers who reset their wages.

Christiano's (2011) analysis is based on a model with no capital accumulation. Here we consider the quantitative effects of a labor income tax in the version of the ACEL model discussed above. Figure 8 depicts the size of the government spending multiplier when there is a one percent increase in government purchases that lasts for the 12 periods during which the zero lower bound binds. The solid line corresponds to the benchmark case in which all taxes are lump sum. The dashed and dotted lines correspond to the cases in which  $\tau_t^L$  rises from zero to one percent in quarters one to 12 and 13 to 24, respectively. The key result is that, regardless of when  $\tau_t^L$  is increased, the multiplier is higher than when taxes are lump sum.

The intuition for why the multiplier goes up when  $\tau_t^L$  increases in periods one to 12 is discussed above. To understand why output falls after period 12 recall that the rise in  $\tau_t^L$  leads to a fall in the real interest rate during the first 12 periods by raising anticipated inflation. This fall induces households to substitute consumption from the future to the present. Consequently output falls after period 12 when the rise in  $\tau_t^L$  is reversed.

Now consider the case where  $\tau_t^L$  rises in periods 12 to 24. An increase in future values of  $\tau_t^L$  raises future marginal cost and inflation. In the presence of staggered pricing the firms that can change their prices in periods one through 12 raise their prices in anticipation of future inflation. As long as the zero bound binds, this effect lowers the real interest rate, thus contributing to a rise in output. Not surprisingly, the effect on the multiplier is smaller than when the rise in  $\tau_t^L$  coincides with the increase in government spending.

The previous discussion makes clear that financing government spending with distortionary labor income taxes would increase, not decrease, the multiplier, at

least in the first 12 quarters. In this sense the main conclusions stressed in Section 5 are robust to allowing for distortionary taxes.

An alternative to increasing taxes on labor income is to raise taxes on capital income. As it turns out, the effects of capital taxes are surprisingly subtle. Outside of the zero bound it does not matter whether firms or households pay the capital income taxes. But, when the zero bound binds it does matter. Recall that  $R_{t+1}^k$  denotes the average rate of return on capital across firms. Let the tax rate on capital be  $\iota_t^k$ . Suppose that firms pay the capital tax. Then, for a given level of  $R_{t+1}^k$ , an increase in  $\iota_t^k$  leads to a fall in the demand for investment goods by firms. In equilibrium this effect leads to a fall in investment, output, marginal cost, and inflation. So, other things equal, an increase in  $\iota_t^k$  can potentially make the zero bound binding or exacerbate an existing zero-bound problem. Note that an increase in the capital tax born by the firms is isomorphic to an increase in the costs of financial intermediation ( $\tau_t^k$ ) that we used in our discussion of the recent financial crisis.<sup>27</sup> So, we have already analyzed this type of capital income tax above. It follows that if an increase in government consumption is financed by a capital income tax paid by firms, then the multiplier is smaller than if lump sum taxes are used.

Now suppose that households pay the capital taxes. Then an increase in  $\iota_t^k$  leads to a reduction in savings and to an increase in consumption, output and inflation. So, other things equal, an increase in  $\iota_t^k$  makes the zero bound less binding if it was binding to begin with. This type of capital income tax is the one considered in Eggertsson (2011). As in the labor income tax case, financing government spending with an increase in the capital income tax rate that is paid by households leads to an increase in the multiplier.

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<sup>27</sup>In making this statement, we ignore the fact that a capital tax rate paid by the firm and resources used in intermediation have different effects on the economy's resource constraint. Recall that in our analysis of the financial crisis we assume this effect is negligible.

We conclude by noting that an obvious alternative to increasing government spending to deal with the zero lower bound problem is to manipulate the demand for goods by varying the time profile of investment tax credits or consumption taxes. Here we briefly comment on the latter.<sup>28</sup> In the context of the Japanese zero lower-bound episode, Feldstein (2003) proposes raising the value-added tax (VAT) by one percent per quarter and simultaneously reducing income tax rates to keep revenue unchanged, continuing this policy for several years until the VAT reaches 20 percent. Correia, Fahri, Nicolini, and Teles (2010) argue that if taxes on consumption, labor, and capital income are state contingent every allocation that can be implemented with a combination of taxes and monetary policy that does not necessarily respect the zero lower bound constraint can also be implemented with a different combination of taxes and monetary policy that does respect the zero lower bound constraint.

It is evident that the policies envisioned by Feldstein (2003) and by Correia et al (2010) were not pursued in the U.S. Implementing these policies would require introducing a national consumption tax.<sup>29</sup> We are skeptical about introducing a new source of national taxation to deal with rare events like the zero-lower-bound problem. Our skepticism stems from the political-economy literature that tries to explain why modern economies do not rely more heavily on consumption taxes (e.g. Brennan and Buchanan (1977) and Krusell, Quadrini, and Rios-Rull (1996)). A key insight from this literature is that if government revenue is used for redistributive purposes, then consumption taxes may be welfare decreasing by comparison with income taxes. Income taxes are attractive precisely because they are more distortionary. Since it is more costly to raise revenues with income taxes,

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<sup>28</sup>See Eggertsson (2011) for a discussion of the effects of investment tax credits.

<sup>29</sup>There are, of course, sales taxes at the state and local level but, presumably, it would have been difficult and time consuming to coordinate changes in these tax rates. There were programs such as cash for clunkers but these were small in scale.

there are less transfers in equilibrium. Krusell et al (1996) emphasize that in their model, switching from an income to a consumption tax system typically does not make the median voter better off. But changing from income to consumption taxes can make everybody worse off.

Many countries already have value-added taxes but even here we are skeptical of the feasibility of the policies proposed by Feldstein (2003) and Correia et al (2010). This skepticism stems from the need to introduce a complicated state-dependent tax policy to deal with the rare occasions in which the zero bound binds. It is possible that a simplified version of the tax policies envisioned by Correia et al (2010) would be desirable. Understanding the quantitative welfare properties of simple tax policies versus increases in government spending as a way of dealing with the zero-bound problem is an important topic that we leave for future research.

## 7. Conclusion

In this paper we argue that the government-spending multiplier can be very large when the nominal interest rates is constant. We focus on a natural case in which the interest rate is constant, which is when the zero lower bound on nominal interest rates binds. In these economies the government-spending multiplier is quite modest when monetary policy is governed by a Taylor rule.

Our analysis abstracts from a host of political economy considerations which might make an increase in government spending less attractive than our analysis indicates. We are keenly aware that it is much easier to start new government programs than to end them. The relative merits of government spending and of different tax policies as a way of dealing with the zero-bound problem remain very much an open issue in the presence of political economy considerations. What our analysis does indicate is that measures designed to increase aggregate demand are

particularly powerful during episodes in which the zero bound binds.

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Figure 1: Simple diagram.

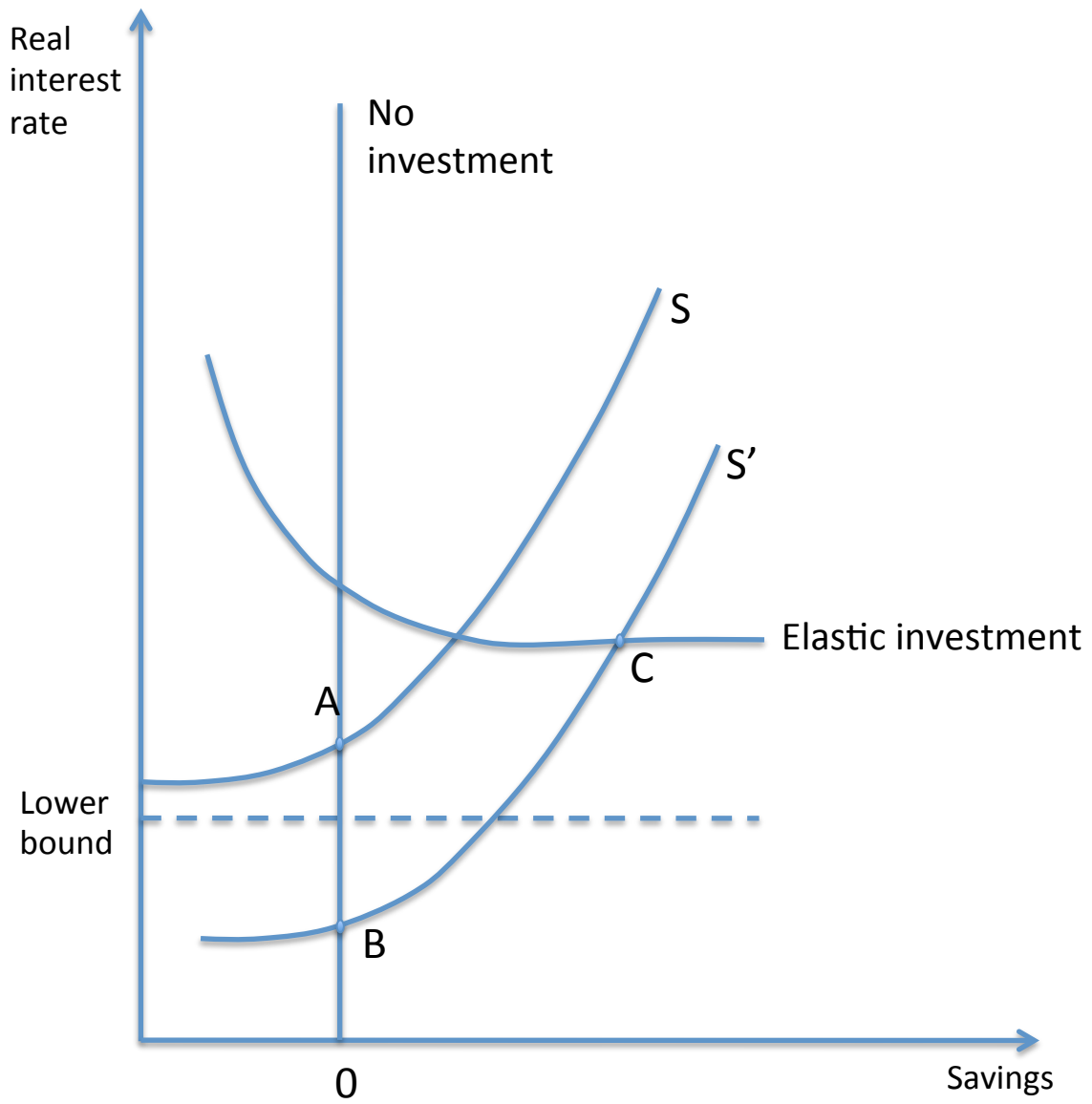


Figure 2: Government spending multiplier when the zero bound is binding (model with no capital).

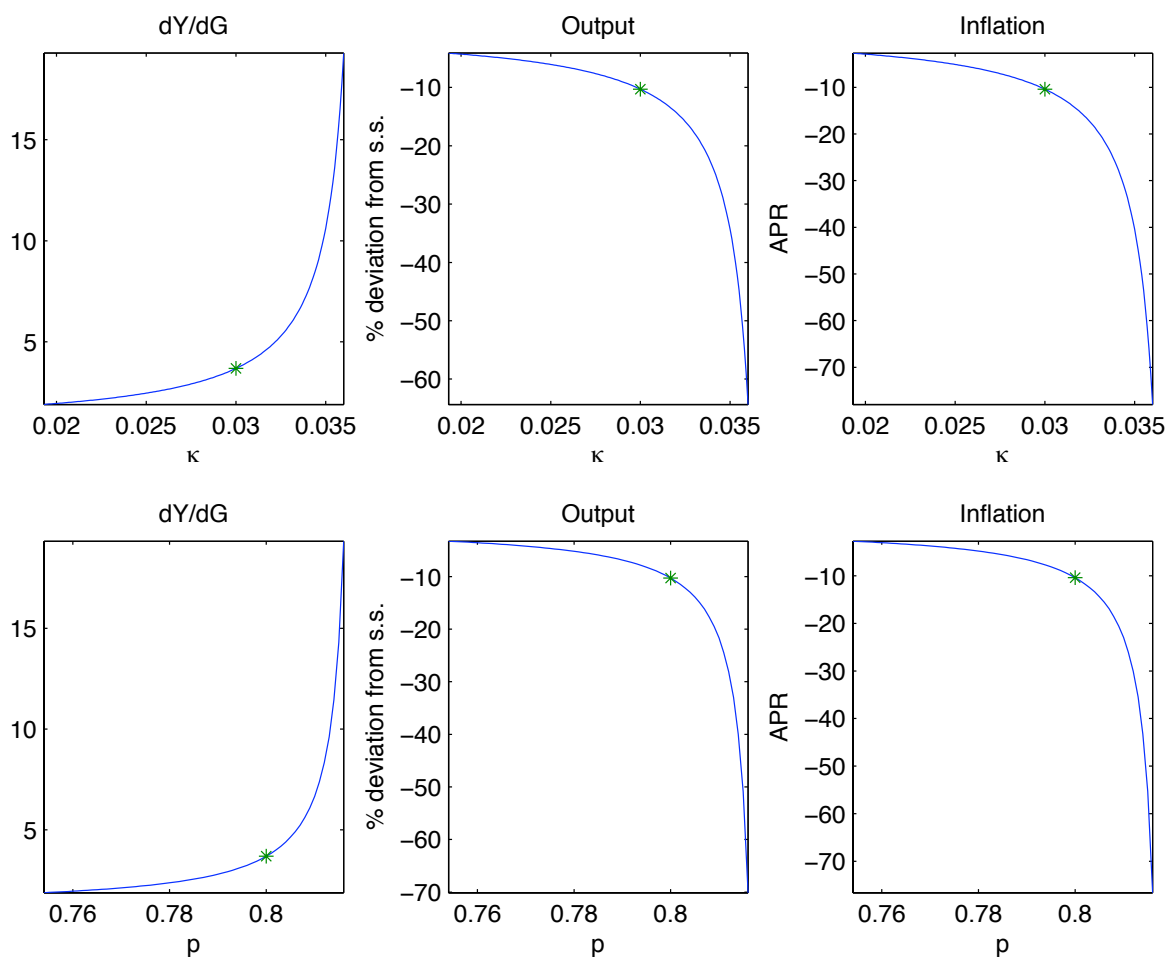


Figure 3: Optimal level of government spending in the zero bound.

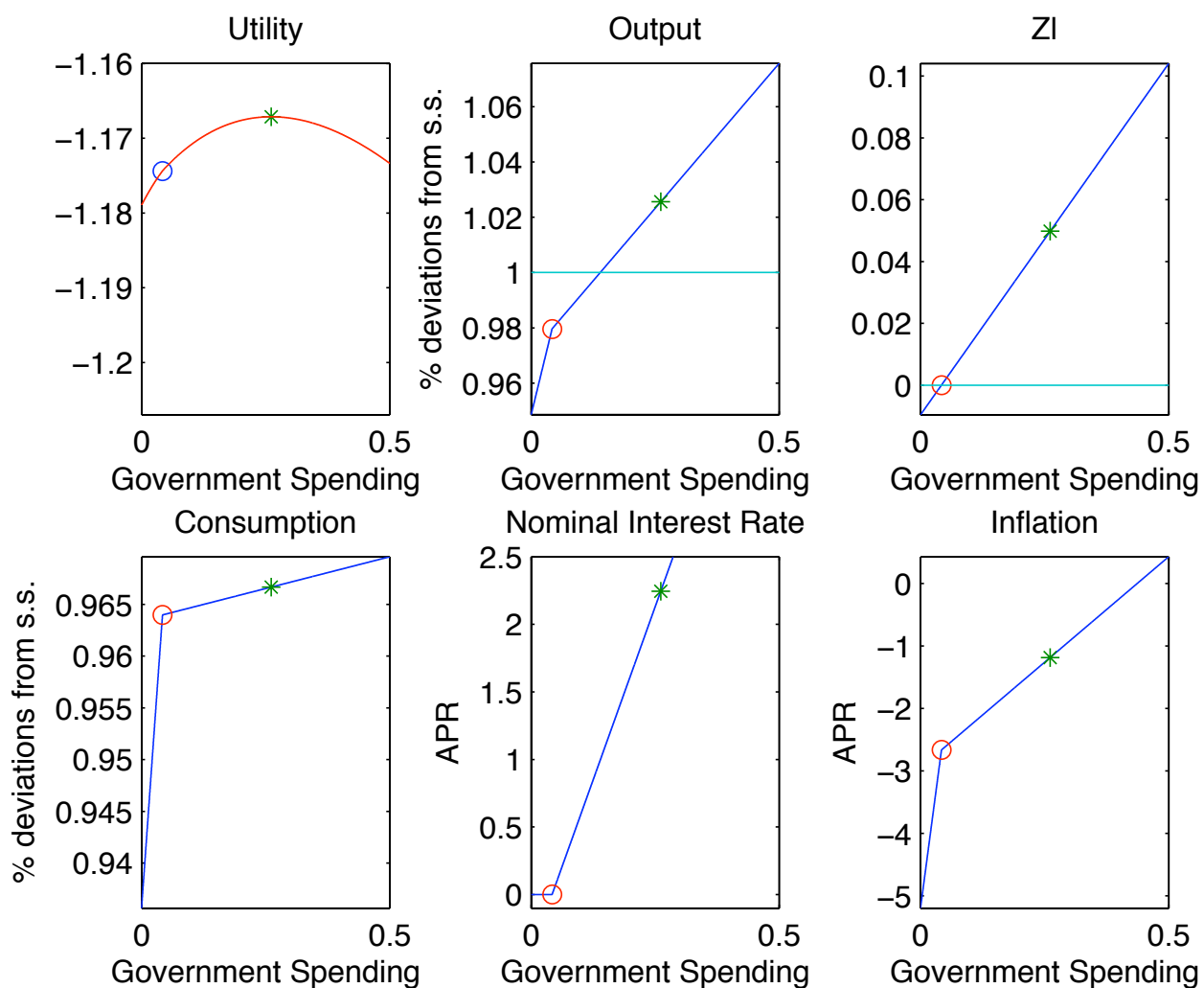


Figure 4: Effect of discount rate shock when the zero bound is binding (model with capital, two types of capital adjustment costs).

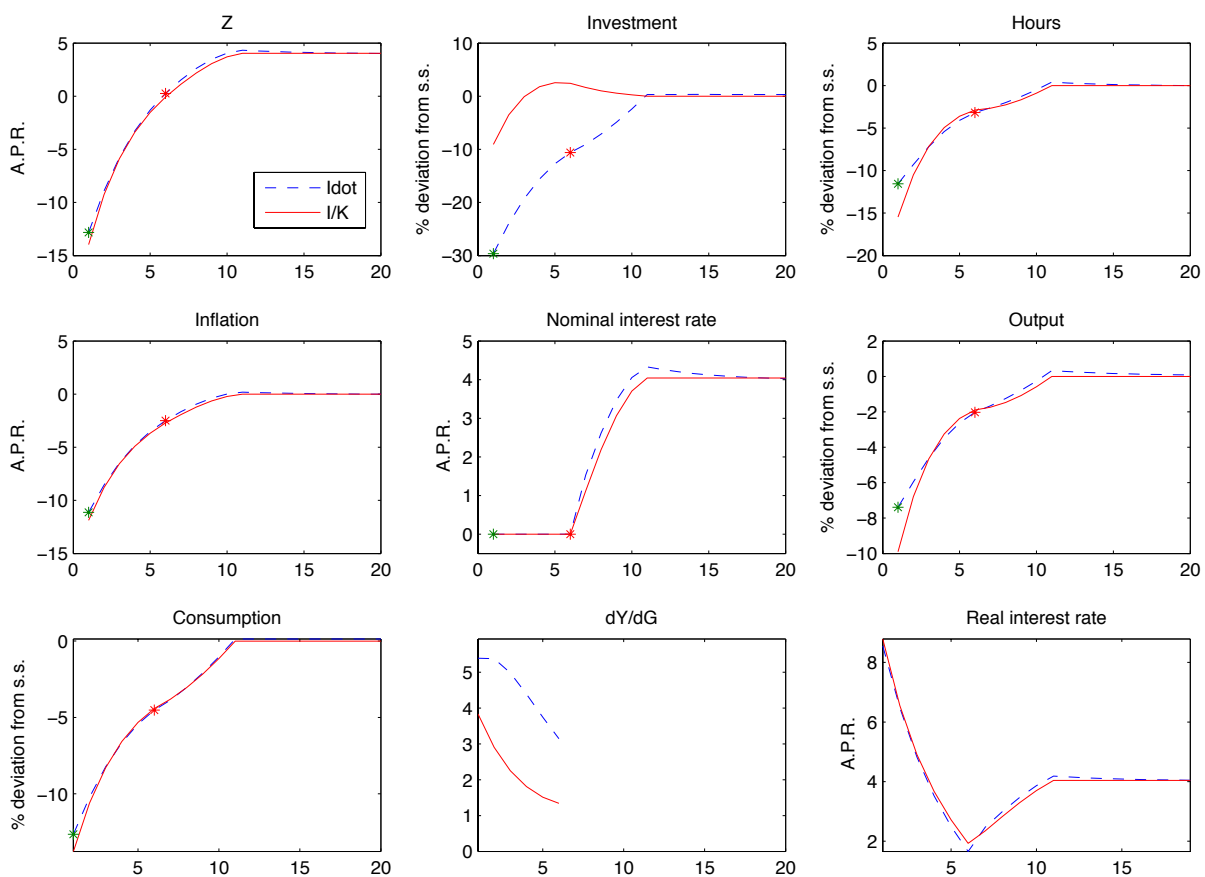


Figure 5: Government spending multiplier in the ACEL model.

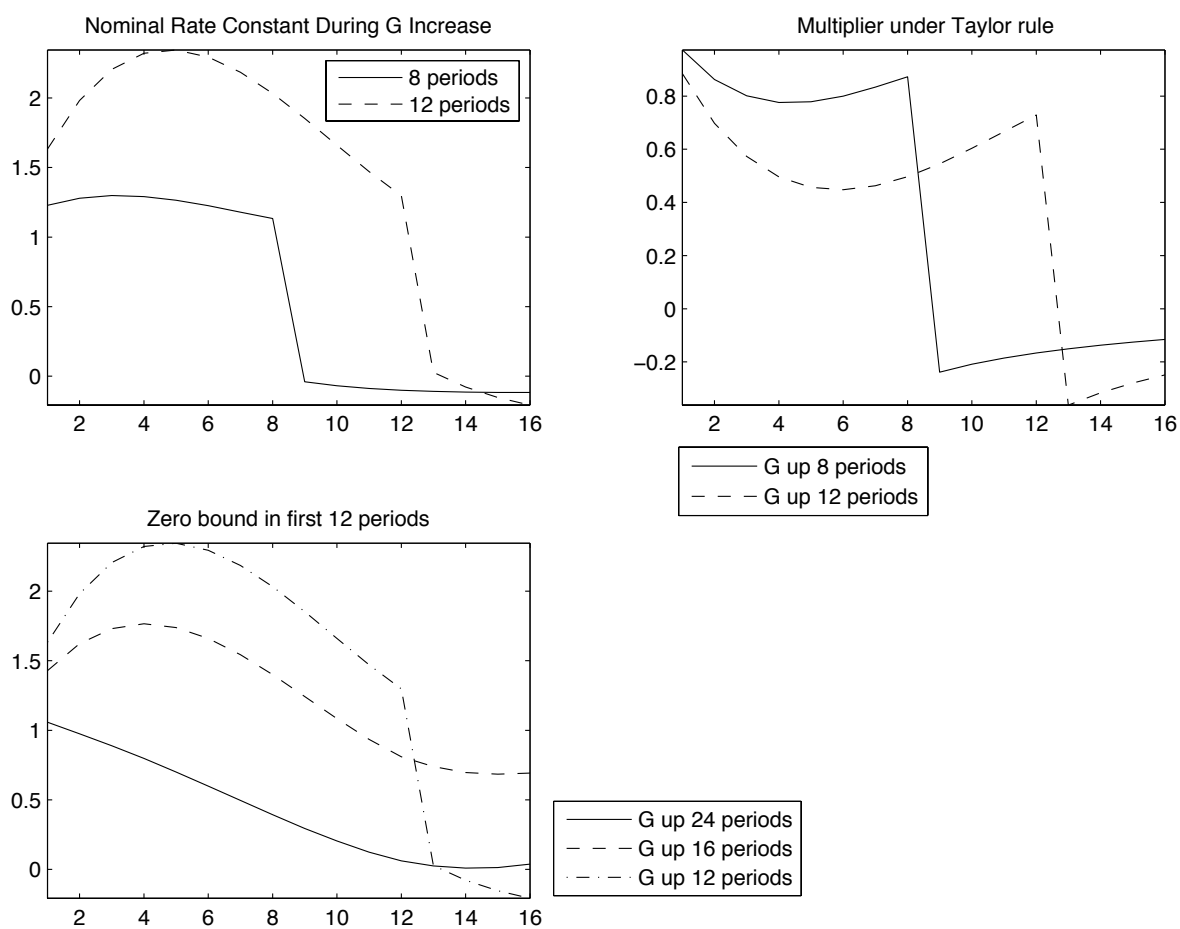




Figure 6: Data and forecasts.

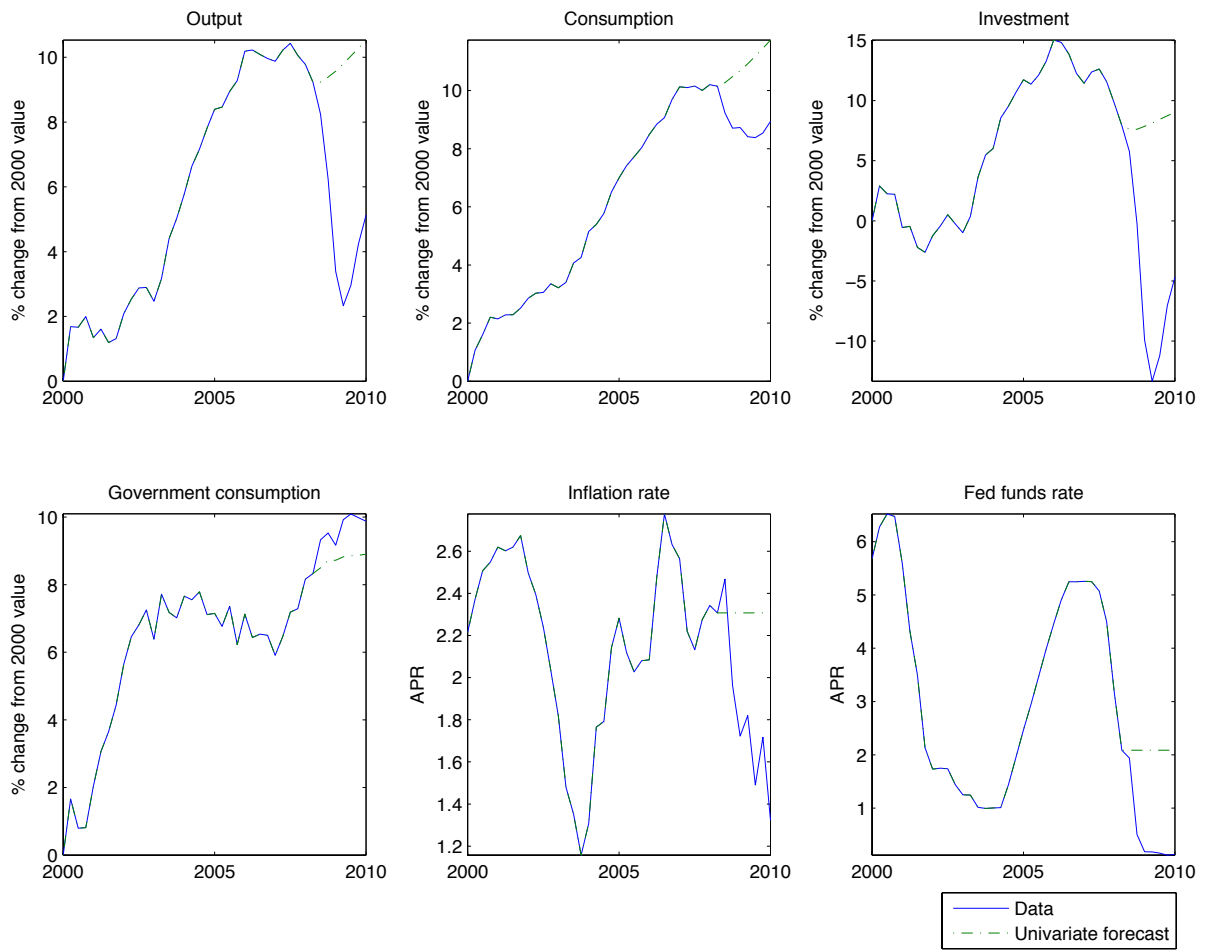


Figure 7: Data and model impulse response functions.

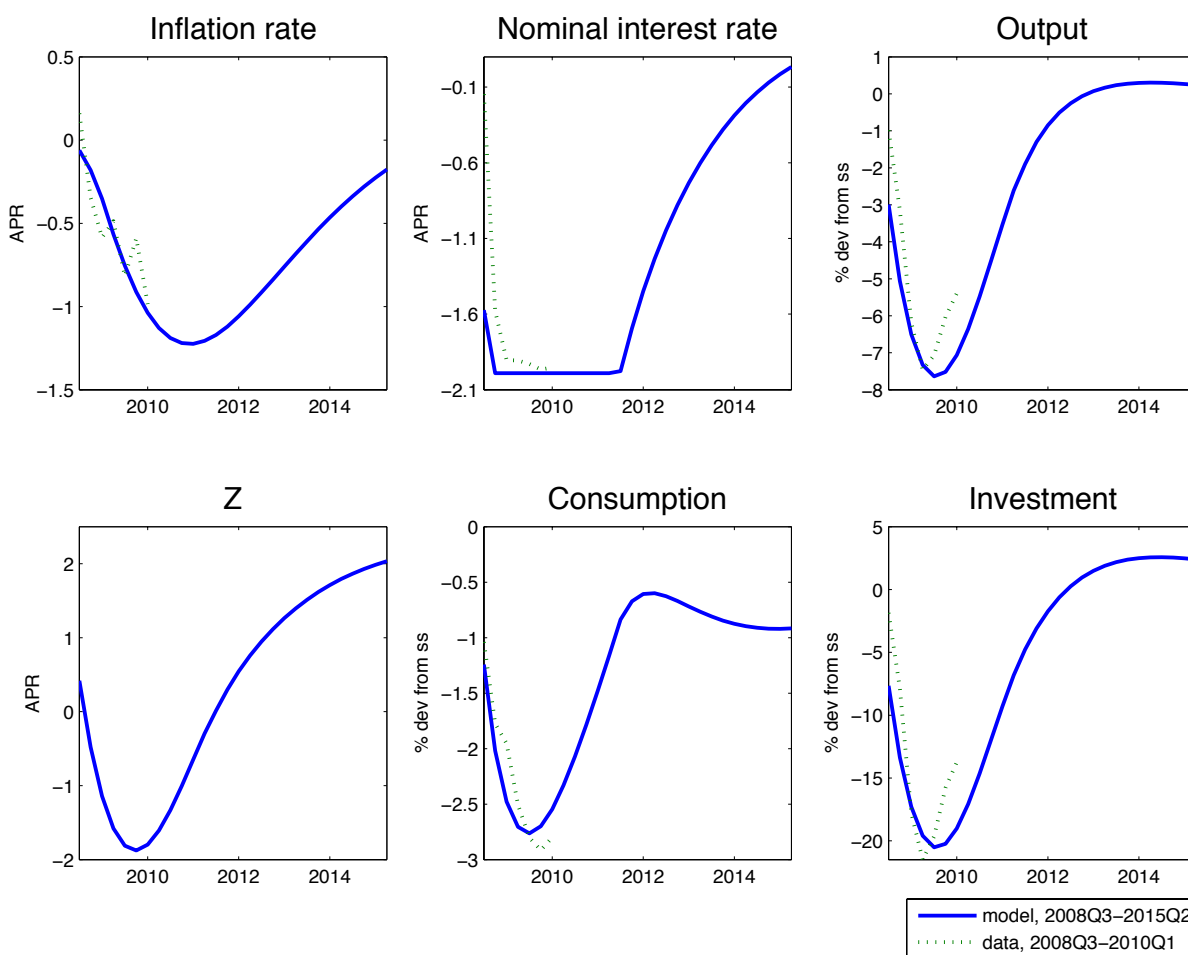


Figure 8: Effect of labor income tax increase on the government spending multiplier when the zero lower bound is binding.

