DNB Working Paper
No. 565 / July 2017

The effects of fiscal policy at the effective lower bound

Dennis Bonam, Jakob de Haan and Beau Soederhuizen

DeNederlandscheBank
EUROSYSTEEM

The effects of fiscal policy at the effective lower bound

Dennis Bonam, Jakob de Haan and Beau Soederhuizen *

* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

Working Paper No. 565

July 2017

De Nederlandsche Bank NV
P.O. Box 98
1000 AB AMSTERDAM
The Netherlands

The effects of fiscal policy at the effective lower bound*

Dennis Bonam[a], Jakob de Haan[a,b] and Beau Soederhuizen[c]

[a] *De Nederlandsche Bank*
[b] *University of Groningen, CESinfo*
[c] *Nyenrode Business University*

5 May 2017

Abstract

We estimate the effects of government consumption and investment shocks during prolonged episodes of low interest rates, which we consider as proxy for the effective lower bound. Using a panel VAR model for 17 advanced countries, in which we include real government spending, output, inflation, and the real interest rate, we find that both the cumulative government consumption and investment multipliers are significantly higher (and exceed unity) when interest rates are persistently low. These results are robust for using different threshold values for the nominal interest rate or the length of the period with low interest rates to proxy the ELB.

Keywords: fiscal multipliers, effective lower bound, panel VAR.
JEL classifications: E6, E62, E65.

* We thank seminar participants at De Nederlandsche Bank for helpful comments. All errors are our own. The views expressed do not necessarily reflect the official position of De Nederlandsche Bank or the Eurosystem.

1 Introduction

Nowadays, many countries still struggle with the fallout of the global financial crisis, facing sluggish economic growth and inflation that is persistently (and sometimes far) below target. As monetary policy increasingly runs out of steam due to the effective lower bound (ELB) on the nominal interest rate and the decreasing effectiveness of unconventional policies (Blinder et al., 2017), several policy makers have called upon fiscal policy to bring the economy back on track. For instance, the vice-governor of the Federal Reserve recently stated: "Certain fiscal policies can increase the potential of the economy and help confront some of our longer-term economic challenges. By raising equilibrium interest rates, such policies may also reduce the probability that the economy, and the Federal Reserve, will have to contend more than is necessary with the effective lower bound on interest rates." (Fischer, 2016).[1] Likewise, in the letter of intent accompanying Juncker's 2016 State of the Union address, the President of the European Commission announced his intention to promote "a positive fiscal stance for the euro area, in support of the monetary policy of the European Central Bank".

Several recent papers suggest that fiscal policy may be very effective when the ELB is binding.[2] For instance, using a New Keynesian DSGE model, Eggertsson (2011) finds that the effects of government spending shocks are much larger under the ELB than under normal circumstances (multiplier of 2.3 vs. 0.48 when interest rates are positive), as they tend to eliminate contractionary expectations. However, studies have reached different conclusions about the relationship between the magnitude of the government spending shock and the size of the multiplier. Whereas Christiano et al. (2011) argue that a greater government spending shock raises the multiplier, Erceg and Lindé (2014) conclude that the multiplier may actually decrease if the fiscal shock becomes larger. The reason is that a larger stimulus puts the economy out of the liquidity trap faster, prompting the central bank to raise the

[1] Similarly, ECB-President Draghi argued in his speech at Jackson Hole in 2014 that "...it would be helpful if fiscal policy could play a greater role alongside monetary policy, and I believe there is scope for this, while taking into account our specific initial conditions and legal constraints" (Draghi, 2014).

[2] The size of the government spending multiplier at the ELB has been shown to depend on the degree of price and wage stickiness (Woodford, 2011).

nominal interest rate and crowd out private spending. Finally, the fiscal multiplier at the ELB might also depend on the composition of the government spending shock. Whereas Coenen et al. (2012) report similar multipliers for government consumption and government investment shocks, other studies find that the size of government investment multipliers may be mitigated by negative supply-side effects, i.e. the expected fall in real marginal costs due to higher public investment. For instance, Albertini et al. (2014) show that the multiplier at the ELB is lower when government spending is productive, while Bouakez et al. (2017) find that public investment shocks can lead to negative output responses at the ELB. This reflects that the negative supply-side effect may outweigh the positive demand-side effect stemming from an increase in future aggregate demand following the fiscal expansion.

This paper provides new empirical evidence on the size of the fiscal policy multiplier at the ELB. In view of the disagreement about the role of the composition of the government spending shock in determining the size of the fiscal multiplier, we consider both government consumption and government investment shocks.Since ELB spells are scarce, we consider prolonged episodes of low interest rates as a proxy for the ELB, following some previous studies on the size of the fiscal multiplier using historical data. In particular, to identify periods when the ELB is binding, we introduce a dummy variable which equals one when the short-term nominal interest rate is below 1 percent for at least 4 consecutive quarters, and zero otherwise. Further, we pool quarterly data from a sample of 17 advanced economies, covering the 1960-2015 period, and use a panel VAR model to estimate fiscal multipliers, in the spirit of Ilzetzki et al. (2013). Our results suggest that both the cumulative government consumption and investment multipliers are higher when interest rates are persistently low. These results are robust to alternative definitions of our ELB dummy in which different threshold values for the nominal interest rate or lengths of ELB spells are considered. We also perform robustness exercises that control for the prevailing monetary regime and the business cycle and find that our main results do not change.

Our work is related to some previous papers that estimate the fiscal multiplier at the ELB using historical data for the US, the UK or Japan to identify ELB spells. For instance, Ramey (2011) estimates a VAR model using US data and finds no evidence of higher multipliers at the ELB, identified as the period between 1939 and 1945, when interest rates were 0.24 per cent on average. Likewise, Ramey and Zubairy (2014) investigate government spending multipliers under interest rates near the ELB for the US. At the ELB, defined as the 1932Q2-1951Q1 and 2008Q4-2015Q4 periods, multipliers are found to be larger than unity. However, Bernardini and Peersman (2015) show that, when controlling for the presence of private debt overhang, these ELB periods do not seem to matter much for the size of the multiplier. For the UK, Crafts and Mills (2013) estimate government spending multipliers during the 1930s and find that they are higher at the ELB, yet below unity (multipliers range between 0.3 and 0.9). Finally, for Japan Miyamoto et al. (2016) find higher multipliers (around 1.5) under the ELB, identified as the 1995Q4-2014Q1 period, than under normal circumstances (around 0.5), while Morita (2015) provides evidence (based on a time-varying VAR) that the effects of fiscal policy are higher under the ELB.

The remainder of the paper is structured as follows. Section 2, provides a theoretical benchmark for the relationship between the fiscal multiplier and the key characteristics used in our empirical analysis to proxy the ELB, i.e. the length of the period with low interest rates and the threshold value for the interest rate. We use this theoretical benchmark to test the robustness of our empirical results when considering alternative definitions of the ELB dummy variable. Section 3 describes the empirical strategy and the data used. Section 4 presents our estimation results and checks the robustness of our estimates. Finally, Section 5 concludes.

2 A theoretical benchmark

Our empirical strategy involves the use of a dummy variable that splits the sample into episodes when an economy faces the ELB and when it does not. This dummy variable is defined by two characteristics: the length of the period with low interest rates, which we denote by $\mathcal{D}$, and the threshold value for the policy rate below which the ELB is considered to be binding, denoted by $\mathcal{T}$. Using a standard New Keynesian model, we briefly investigate the role of these two ELB characteristics for the size of the fiscal multiplier.

In the first part of this section, we provide an overview of the model. Since the model is pretty standard, we defer a full description of the model to the Appendix. In the second part, we use the model to illustrate the channels through which the ELB may amplify the effects of fiscal policy shocks, and discuss how $\mathcal{D}$ and $\mathcal{T}$ affect the size of the fiscal multiplier. The outcome of this exercise serves as a theoretical benchmark to evaluate the robustness of our empirical results.

2.1 Model

The model consists of three types of agents: households, firms and the government. A representative, infinitely-lived household chooses consumption, hours worked, investment in nominal one-period bonds and real private capital in order to maximize expected life-time utility. The household faces exogenous (persistent) preference shocks and two real frictions, i.e. persistence in consumption due to habit formation and investment adjustment costs.

Each household owns a firm which produces differentiated intermediate goods. These goods are sold in monopolistic markets and prices are chosen optimally by the firm to maximize profits. Firms face a price-setting constraint that prohibits a random (yet constant) fraction of firms to adjust their price in each period. This nominal friction allows fiscal and monetary policy to have real (short-run) effects. Intermediate goods are produced using labor, private capital and public capital as inputs.

The government consists of a fiscal and monetary authority. The fiscal authority levies lump-sum taxes to finance government consumption and investment expenditures. The fiscal budget is balanced each period. Further, we assume that public consumption and investment follow exogenous and stationary auto-regressive processes. The monetary authority aims to stabilize inflation and output by adjusting the nominal interest rate according to a Taylor-type rule (Taylor, 1993) that relates the interest rate to deviations of inflation and output from their (exogenous) targets. The interest rate may be subject to an effective lower bound. [3] As a benchmark, we set the threshold for the ELB at $\mathcal{T} = 0$, i.e. the ELB is binding when the policy rate is equal to or below 0 percent. The duration of the ELB spell is denoted by $\mathcal{D}$. Since this model faces a constraint which is occasionally binding, we use the OccBin toolkit of Guerrieri and Iacoviello (2015) to solve the model.

2.2 The effects of fiscal shocks at the effective lower bound

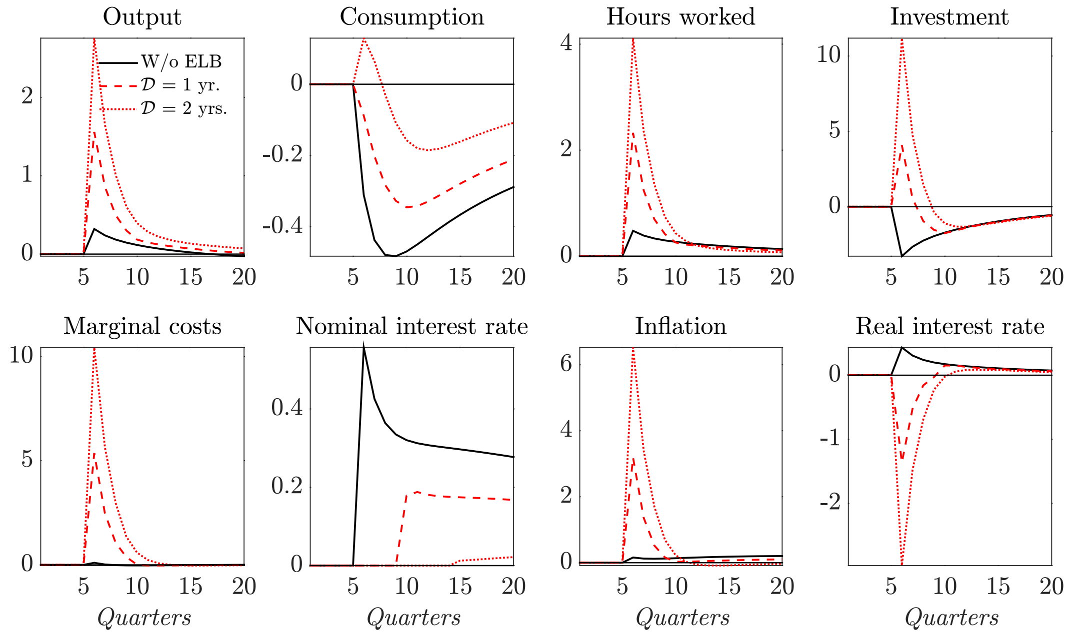
We simulate the responses of selected variables to government consumption and investment shocks and show the outcomes under this scenario as percentage deviation of the results for these variables under the baseline scenario. We consider the outcomes of government spending shocks when the effective lower bound is not binding and when the ELB is binding. In the former case, we compare the responses under a scenario in which either a transient government consumption or investment shock occurs in the sixth period (which is 1 percent of steady-state output) with those under the baseline scenario. In the latter case, the baseline scenario includes a preference shock for households that pushes the economy towards the ELB. The alternative scenario also includes this preference shock, together with one of the two fiscal shocks.

Figure 1 shows the impulse responses to a government consumption shock. The theoretical model predicts an increase in output following a rise in government consumption. When the ELB is binding, the output response is larger and the impact multiplier exceeds unity, especially if the duration of the ELB spell is relatively long.

The results suggest that, due to an increase in aggregate demand, labor demand goes up which raises real wages, marginal costs, and hours worked. Moreover, labor supply rises due to a negative wealth effect on consumption: as households anticipate higher future taxes

[3] This is caused by a preference shock that raises the desire of households to save. See Christiano et al. (2011) for a similar approach to generate ELB episodes.

Figure 1: The effects of a government consumption shock

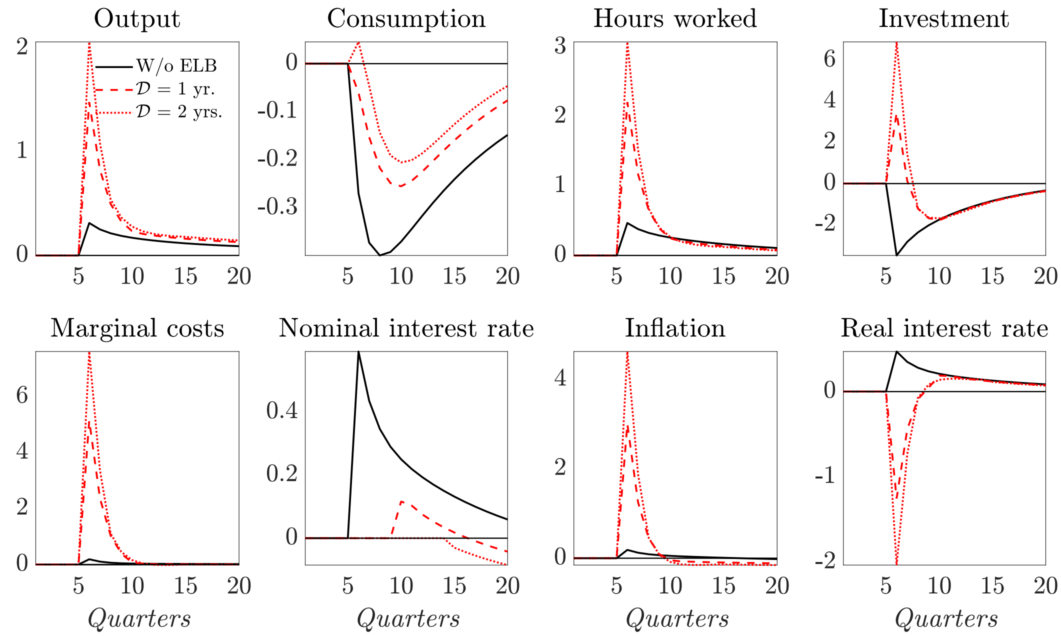


Note: The government consumption shock is scaled to be 1 percent of steady-state output. The impulse responses show deviations from the baseline scenario without fiscal shocks (in percentage points). The nominal and real interest rate and inflation are annualized.

(required to finance the current fiscal expansion), they are willing to work more to smooth life-time consumption. The negative wealth effect also causes consumption to fall in response to the fiscal shock. However, when the ELB is binding, consumption falls by less and can even respond positively to the government consumption shock if the duration of the ELB spell is sufficiently long. The possibility of a positive consumption response arises from a rise in inflation (due to higher marginal costs) which, given a fixed nominal interest rate, lowers the real interest rate. This *real interest rate effect* on consumption counteracts the negative wealth effect, allowing the fiscal multiplier to exceed unity.

The response of private investment to the government consumption shock can be explained by the real interest rate effect as well. When the ELB is not binding, investment falls due to the rise in the policy rate and the negative wealth effect. In contrast, when the ELB is binding, investment rises as the increase in aggregate demand raises the net return on capital. Thus, the presence of a binding ELB reduces the crowding-out effect of fiscal policy on private spending.

Figure 2: The effects of a government investment shock



Note: The government investment shock is scaled to be 1 percent of steady-state output. The impulse responses show deviations from the baseline scenario without fiscal shocks (in percentage points). The nominal and real interest rate and inflation are annualized.

Figure 2 shows the responses to a government investment shock under different assumptions about the path of the interest rate. These responses are quite similar to those following a government consumption shock: the government investment multiplier is higher when the ELB is binding than when it is not. Eggertsson (2011), however, cautions for the use of supply-side policies when an economy faces the ELB. On the one hand, since government investment reduces firms' real marginal costs, it tends to reduce inflation (expectations) and thereby *raise* the real interest rate. On the other hand, an increase in public investment raises aggregate demand, which raises real marginal costs and inflation, and thereby lowers the real interest rate. These counteracting supply and demand effects both determine the overall response of output to the government investment shock. Which of these two effects dominates depends, among other things, on the duration of the ELB spell, $\mathcal{D}$.

Figure 3 plots the cumulative fiscal multiplier as a function of $\mathcal{D}$. The cumulative multiplier is calculated as the discounted sum of the output responses over 20 quarters. As the

Figure 3: Cumulative fiscal multipliers and the role of the ELB duration, $\mathcal{D}$

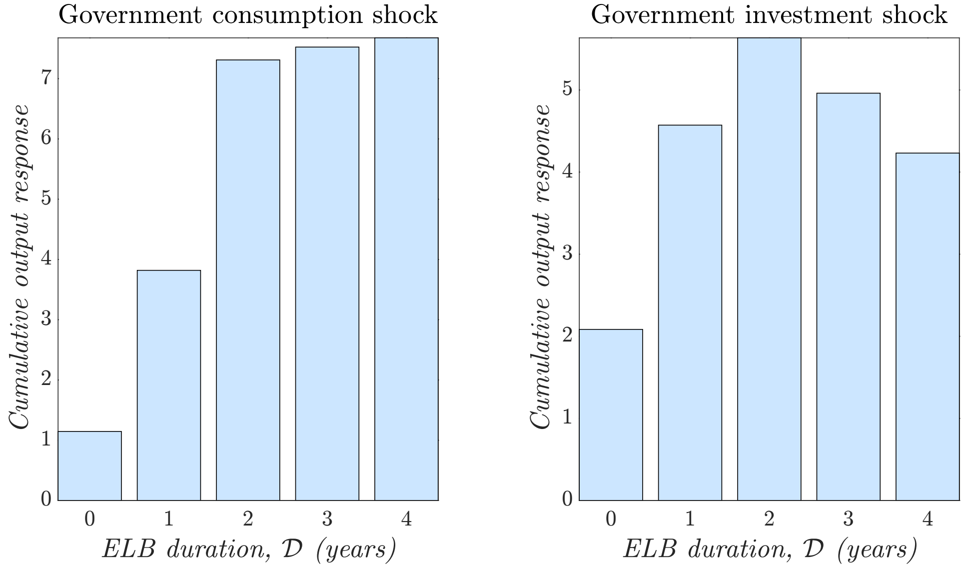
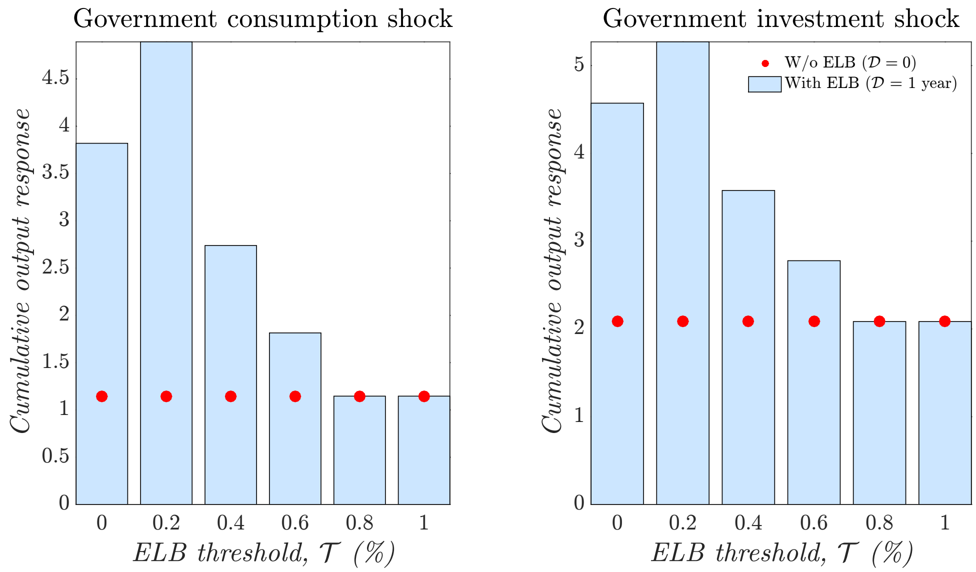


figure shows, increasing the duration of the ELB spell raises the cumulative output response to a government consumption shock (left-hand side panel). Intuitively, the longer it takes before the economy escapes the ELB, the stronger becomes the real interest rate effect and thus the smaller are the crowding-out effects of the fiscal expansion. However, the marginal effect of $\mathcal{D}$ on the cumulative government investment multiplier turns negative once $\mathcal{D}$ exceeds a certain threshold. Therefore, these numerical results indicate that the negative supply-side effects discussed by Eggertsson (2011) start to bite once an economy is stuck in a liquidity trap for a long time.

Finally, Figure4 plots the cumulative fiscal multiplier as a function of the ELB threshold value, $\mathcal{T}$, while keeping the duration of the ELB fixed at $\mathcal{D} = 1$ year. The results suggest that the cumulative output response to both a government spending and investment shock falls as the threshold rises. For $\mathcal{T}$ sufficiently high, leaving sufficient scope for the monetary authority to counteract the fiscal shock, the cumulative multiplier is reduced to the value it would obtain if the ELB were not binding (indicated by the red dots).

Figure 4: Cumulative fiscal multipliers and the role of the ELB threshold, $\mathcal{T}$



3 Empirical strategy

3.1 A proxy for the effective lower bound

Although policy rates set by central banks have been historically low in recent years, prolonged spells at the ELB are scarce. With the Bank of Japan during the 1990s being a notable exception, none of the world's major central banks were confronted with the ELB during the five decades preceding the Great Recession of 2008.

Therefore, in order to assess the effects of fiscal policy at the ELB, we need to define a suitable proxy for the ELB. We consider an economy as being bound by the ELB when *the nominal policy rate is below 1 percent during at least 4 consecutive quarters*. Hence, letting $R_{n,t}$ denote the nominal interest rate set by the central bank at quarter t in country n, the dummy variable $D_{n,t}$ used in our analysis to identify ELB episodes is determined as follows:

$$D_{n,t} = \begin{cases} 1 & \text{if } R_{n,t-s} < 1\% \text{ for } s \in \{0, 1, 2, 3\}, \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

We use this dummy to split our sample into two sub-samples: one with and one without prolonged episodes of low interest rates. As a robustness check, we experiment with alternative proxies for the ELB by altering both the threshold for the policy rate and the number of consecutive quarters during which the policy rate must be below this threshold. As we show below, our results do not change in a qualitative sense when considering these alternative proxies.[4]

Although our proxy defined by (1) may capture periods when the ELB is *not* binding, its implications for the effects of fiscal policy are in line with conventional Keynesian theory on the role of the ELB. One could interpret our proxy for the ELB as capturing the case in which the LM can move only within a limited range. Therefore, the monetary response to fiscal shocks is limited, which allows the fiscal multiplier to be larger compared to the case in which movements of the LM curve are unconstrained. Thus, even though our proxy does not necessarily refer to a situation where interest rates are stuck at the ELB, it does limit the range over which interest rates can be adjusted.

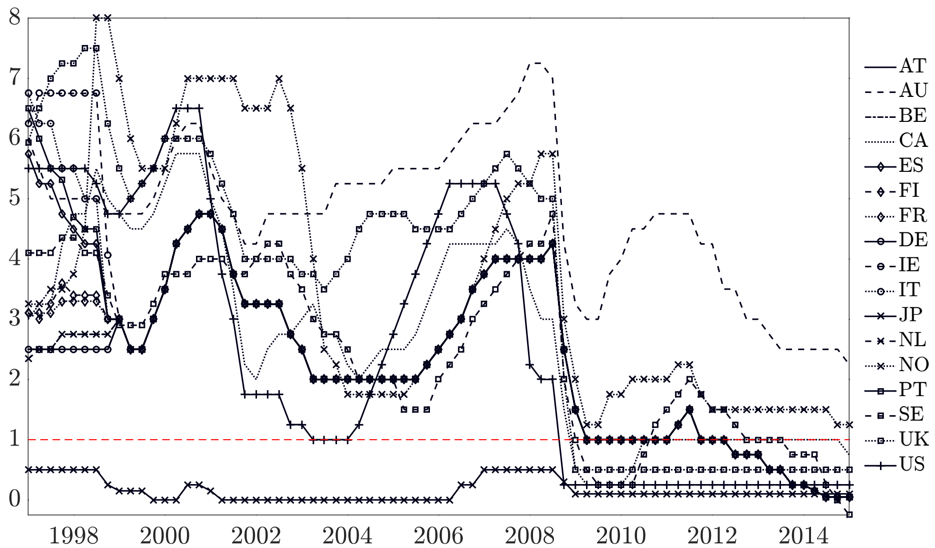
The top panel of Figure 5 shows the evolution of the nominal policy interest rate, for the group of advanced economies that we consider in the empirical analysis below, between 1997Q1 and 2015Q1 (during which data for all countries are available). The red horizontal dashed line shows the threshold value for the interest rate that is used in the definition of the ELB proxy. The figure illustrates the sharp monetary response to the 2008 crisis in most of the advanced world. The bottom panel shows the fraction of time each country has spent at the ELB during this period, according to our proxy formalized by (1). The Japanese economy faced the ELB throughout all quarters between 1997Q1 and 2015Q1. The euro area countries spent the same number of quarters at the ELB, which occurred between 2013 and 2015, reflecting that these countries have a common monetary policy.[5] For the US and

[4] We also considered other proxies for the ELB, such as a dummy variable for periods when inflation drops below 1 or 2 percent (see, for instance, Qazizada and Stockhammer, 2015), but decided that they are problematic. For instance, this dummy would be 1 for the Netherlands in the early and mid 1980s, while interest rates at the time were well above 5 percent.

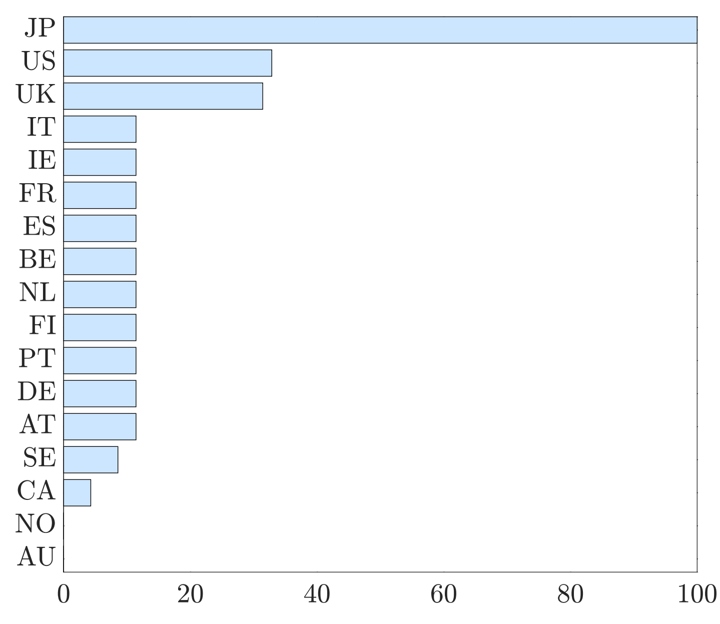
[5] For this reason, we also exclude the euro area countries (except for Germany) from the sample in one of our robustness exercises discussed below. This does not qualitatively change our results.

Figure 5: Nominal interest rates and ELB incidence

(a) Nominal interest rates (%)



(b) Fraction of time spent in ELB spells (%), 1997Q1-2015Q1



Note: Countries are assumed to face the ELB when the policy rate set by the central bank is below 1 percent for at least 4 consecutive quarters, see (1). *Source*: Datastream, OECD Quarterly National Accounts Database and own calculations.

the UK, one ELB spell is identified which started around 2009.

3.2 A panel VAR model

Estimating fiscal multipliers, defined as the percentage change in aggregate output due to a 1 percent change in government spending (as a share of output), is made difficult due to problems of endogeneity. The dynamics of fiscal variables are, typically, not determined by exogenous stochastic processes, yet depend on the, potentially country-specific and time-varying, institutional framework that defines how fiscal policy responds to changes in economic conditions and vice versa. Throughout the years, various methods have been proposed to isolate these endogenous responses of fiscal policy (see e.g. Perotti, 2008, Hall, 2009 and Hebous, 2011, for an overview). Of these methods, the Vector Autoregression (VAR) model has become the most popular and frequently used method to estimate the effects of fiscal policy shocks (Stock and Watson, 2001; Perotti, 2008; Ilzetzki et al., 2013).

The VAR model is a system of linear equations in which the dependent variables are a function of their own lags and those of the other dependent variables. This system can be estimated by OLS which yields the variance-covariance matrix of the residuals of each equation, Σ. Since these residuals may be correlated with each other, certain identifying assumptions on Σ need to be imposed in order to recover the shocks from the estimated residuals. A commonly used approach, and the one followed here, transforms Σ to a lower-triangular matrix through application of the Cholesky decomposition.[6] Once transformed this way, the variable ordered first in the VAR responds to its own shocks contemporaneously and to changes in the other variables with a lag. The second variable responds contemporaneously to the first variable and its own shock, the third variable to the first two variables and its own shock, and so on. This decomposition therefore implies that the variable ordered first can be considered truly 'exogenous'.

One of the major problems of VAR models is that they can become quickly over-parameterized,

[6] Other common restrictions are long-run restrictions (Blanchard and Quah, 1993), theory based restrictions (Blanchard and Perotti, 2002), and sign restrictions (Mountford and Uhlig, 2009).

especially if the number of variables and lags included in the VAR are large. Having many parameters to estimate reduces the degrees of freedom and thereby the likelihood of obtaining significant estimates. This can be particularly problematic in our case, since we split the sample into periods in which the ELB is present and when it is not, which reduces the number of observations. In order to maintain a sufficiently large sample size, we follow Beetsma et al. (2008) and Ilzetzki et al. (2013), among others, and pool data from a panel of 17 advanced economies. In addition, we keep the size of the VAR model limited by including only four variables: real government consumption, $g_{n,t}$, real aggregate output, $y_{n,t}$, inflation, $\pi_{n,t}$, and the real interest rate, $r_{n,t}$. The inclusion of inflation and the real interest rate helps identifying the channels through which fiscal shocks are transmitted to the economy.

Having the variables ordered such that $g_{n,t}$ enters the model first, $y_{n,t}$ second, $\pi_{n,t}$ third and $r_{n,t}$ last, we implicitly assume government consumption to be unaffected contemporaneously in period t by any of the other variables. The intuition here is that fiscal policy, when responding to economic conditions, is often characterized by decision lags as fiscal policy measures need to be approved by parliament, and might be encumbered by implementation lags as well. Output, on the other hand, may respond to fiscal shocks immediately, yet is assumed to affect pricing decisions, and thereby inflation, only with a lag. Finally, once changes in output and inflation are observed, the (real) interest rate is assumed to respond accordingly.

The VAR model is written as follows:

$$AY_{n,t} = \sum_{k=1}^{K} B_k Y_{n,t-k} + \sum_{m=1}^{M} \tilde{B}_m Y_{n,t-m} D_{n,t-m} + C\varepsilon_{n,t}, \tag{2}$$

with $Y_{n,t} = [g_{n,t} \; y_{n,t} \; \pi_{n,t} \; r_{n,t}]'$, and where $D_{n,t}$ is a dummy variable that equals 1 if the ELB is binding and 0 otherwise, see (1). The matrices B_k and $\tilde{B}_m$ govern the dynamic responses to the k^{th} and m^{th} lags of the endogenous variables, which may depend on whether the ELB is binding or not. The matrix A describes the contemporaneous, and therefore endogenous, relationships between government consumption, output, inflation and the real interest rate. The matrix C is diagonal, which implies that the structural shocks, $\varepsilon_{n,t}$, are uncorrelated. To recover these shocks, Equation (2) is estimated in reduced form, i.e.[7]

$$Y_{n,t} = A^{-1}\left[\sum_{k=1}^{K} B_k Y_{n,t-k} + \sum_{m=1}^{M} \tilde{B}_m Y_{n,t-m} D_{n,t-m}\right] + e_{n,t}, \tag{3}$$

where $e_{n,t}$ now denotes a vector containing the reduced-form shocks. In order to find the relationship between $e_{n,t}$ and $\varepsilon_{n,t}$, i.e. $\varepsilon_{n,t} = C^{-1}Ae_{n,t}$, we apply the Cholesky decomposition on the variance-covariance matrix of $e_{n,t}$.[8] As in Ilzetzki et al. (2013), we assume the matrices A, B_k, $\tilde{B}_m$ and C are time invariant and the same for all countries.

The lag structure is determined by Akaike Information Criterion. This criterion suggests an optimal lag length of $K = M = 5$. Since we use quarterly data, including five lags seems sufficient to capture the dynamic relationships of the endogenous variables. Using other lags gives similar results (available on request).

3.3 Data description

To estimate Equation (3), we use quarterly data, covering 1960Q1-2015Q1, for 17 countries: Australia, Austria, Belgium, Canada, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, the UK and the US. For some countries the sample period is shorter, most notably for Canada, Finland and Norway for which data is available only after the early 1990s.

Besides data availability, the selection of countries for our analysis is based on the prevailing monetary regime. Countries operating under a totally fixed exchange rate regime,

[7] In particular, we estimate the reduced-form model given by Equation (3) using fixed-effects panel OLS.

[8] The Cholesky decomposition assumes that A has the following form:

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix},$$

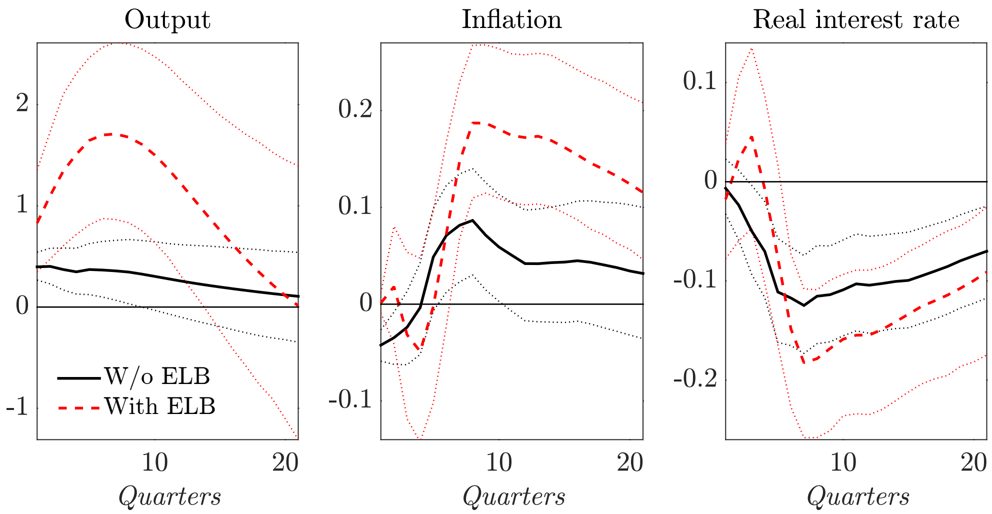
and that C is the identity matrix.

for instance, were discarded from the sample. This is because, in that case, policy rates are generally unresponsive to fiscal shocks, regardless of whether the ELB is binding or not, as monetary policy is committed to keep the exchange rate peg. The distinction between the effects of fiscal shocks with and without a binding ELB would thus be less apparent. In contrast, policy rates are more likely to respond to fiscal shocks in countries with an inflation targeting regime, insofar as such shocks affect inflation, yet only when the ELB is not binding.

Note that, for the countries in our sample that adopted the euro, it is not clear how the monetary regime should be characterized. Since the European Central Bank sets the policy rate for the euro area as a whole, one could assume monetary policy to respond to national fiscal expansions, provided the ELB is not binding. However, for smaller member states, fiscal expansions are probably too small to elicit a change in union-wide inflation and thus provoke an interest rate response from the ECB, even if the ELB is not binding. Although this potential identification problem warrants exclusion of countries belonging to a currency union from our sample, doing so does not change our results (see Section 4).

For aggregate output, $y_{n,t}$, we use data on gross domestic product (GDP) in real terms, based on chained-volume estimates. For government consumption (investment), $g_{n,t}$, data on general government final consumption (investment) expenditure is used. Both series are adjusted for seasonal effects and a quadratic trend. We use the GDP deflator to transform nominal series into real terms. Inflation, $\pi_{n,t}$, is calculated as the year-on-year percentage change in the consumer price index (all items). The real interest rate, $r_{n,t}$, is calculated as the difference between the nominal policy interest rate and the inflation rate in the subsequent period, i.e. $r_{n,t} = R_{n,t} - \pi_{n,t+1}$. All data is retrieved from Datastream and (for missing observations) the OECD Quarterly National Accounts dataset.

Figure 6: Impulse responses to a government consumption shock



Note: The figure shows the discounted cumulative responses to an increase in government consumption (of 1 percent of GDP), when interest rates are at the effective lower bound and when they are not. The dotted lines show the 90% confidence interval.

4 Estimation results

4.1 The effects of government consumption

This section discusses the effects of an increase in government consumption by evaluating the impulse response functions generated by the VAR model presented in Section 3. We focus on the evolution of the cumulative fiscal multiplier, discounted by the short-term interbank offered rate, which is defined as follows:

$$\text{cumulative multiplier}\,(T) = \frac{\sum_{t=0}^{T} (1+i)^{-t}\, \Delta y_t}{\sum_{t=0}^{T} (1+i)^{-t}\, \Delta g_t},$$

where T denotes the impulse response horizon and i the median short-term interbank offered rate in the sample. We scale the cumulative multiplier by the average ratio between government consumption and GDP, such that the size of the shock is measured as a percentage of GDP. Figure 6 shows the results.

The figure suggests that the response of GDP to the government consumption shock is positive and significant, no matter whether the ELB is binding or not. The positive response of GDP reflects that an increase in aggregate demand, provoked by the fiscal expansion, drives up production and expected marginal costs, and leads to an increase in inflation. Consequently, the real interest rate falls, which raises aggregate demand and production further, and also raises private spending.

However, the size of the multiplier depends on the ELB being binding or nor. When interest rates are not at their effective lower bound, a monetary authority that aims to stabilize inflation would be free to raise the nominal interest rate in an attempt to prevent inflation from drifting too far away from target. Therefore, through the contractionary monetary policy response, the fiscal expansion crowds out private consumption and investment which limits the size of the fiscal multiplier.

Figure 6 reveals that, when the economy is not at the ELB, the impact multiplier (i.e. the output response to a fiscal shock in the first period) is well below unity, around 0.4 (solid line). In the quarters that follow, the cumulative multiplier slowly declines and is no longer significantly different from zero after two years, reflecting that fiscal policy only has short-run effects on the real economy (Fatás and Mihov, 2001; Blanchard and Perotti, 2002; De Castro and de Cos, 2008). This long-run 'fiscal neutrality' can be explained by the rise in future taxes needed to finance the fiscal expansion (Uhlig, 2010).

The results are quite different when the economy faces the ELB according to our definition in (1). With the scope for interest rate adjustments more limited, the monetary policy response to the fiscal shock is less pronounced and so the crowding-out effect on private spending is mitigated. As shown in Figure 6, the response of GDP to the government consumption shock is significantly stronger under the ELB (dashed line) than in the absence of the ELB. In fact, after about two years following the shock, the cumulative fiscal multiplier peaks at 1.7, compared to a peak of 0.4 in the baseline scenario. The difference between these maximum cumulative multipliers is significant.

Note also the hump-shaped response of GDP to the fiscal shock in the presence of the ELB. This observed persistence can be explained by a pro-cyclical *real interest rate effect* that amplifies the rise in aggregate demand and inflation (expectations). Only after some time, when monetary policy has responded to changes in inflation, do the effects of the fiscal shock die out.

The results presented in Figure 6 confirm existing theoretical contributions on the implications of the ELB for the effects of fiscal policy and are in line with the theoretical results shown in Figure 1: the response of GDP to a government consumption shock is larger under the ELB due to the absence of a potentially counteracting monetary policy response and a pro-cyclical real interest rate effect. Since the crowding-out effects of fiscal policy on private spending are more limited under the ELB, the fiscal multiplier can exceed unity.

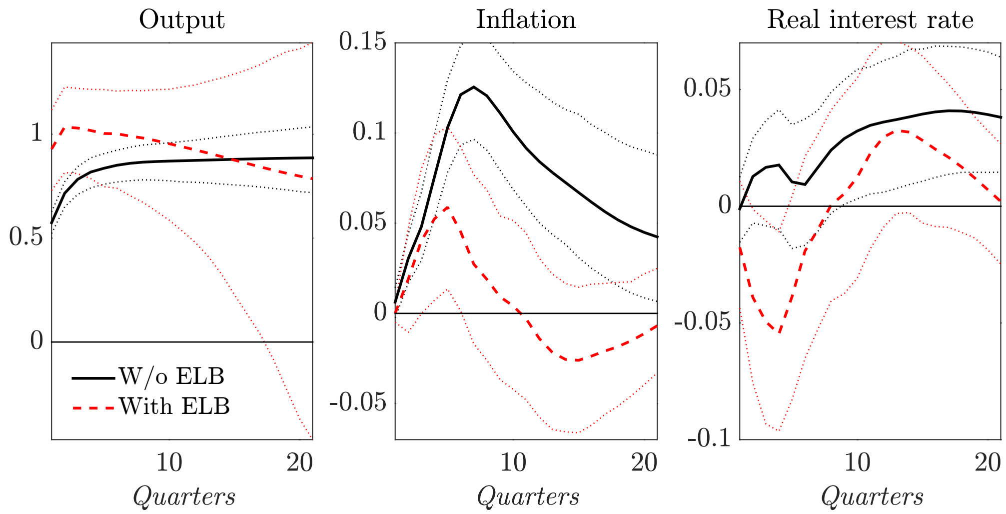
4.2 The effects of government investment

We now investigate the responses to a government investment shock (of 1 percent of GDP). Following Ilzetzki et al. (2013), we add government investment, $i^g_{n,t}$, to the VAR model (3) and assume $i^g_{n,t}$ enters before the other variables, such that $Y_{n,t} = \left[i^g_{n,t} \; g_{n,t} \; y_{n,t} \; \pi_{n,t} \; r_{n,t} \right]'$. For this model, the AIC suggests $K = 6$ and $M = 8$, i.e. an optimal lag length of 6 quarters for the sample without the ELB and 8 quarters for the sample with the ELB. In order to make the two samples comparable, we set $K = M = 6$. The results for both lag structures are, however, very similar.

As shown in Figure 7, government investment raises GDP, both when nominal interest rates are at their effective lower bound and when they are not, but the response of GDP is significantly more pronounced under the ELB. Raising government investment directly increases aggregate demand. Consequently, inflation rises, which, given the limited response of the nominal interest rate, puts downward pressure on the real interest rate, thereby stimulating private expenditures. The latter, in turn, allows for the fiscal multiplier to exceed unity. We find a maximum cumulative government investment multiplier of 1.03 at the ELB, compared to a peak of 0.9 away from the ELB.

Note that investments (both public and private) also tend to reduce real marginal costs, thereby reducing inflation (expectations) and thus *raising* the real interest rate. The results

Figure 7: Impulse responses to a government investment shock



Note: The figure shows the discounted cumulative responses to an increase in government investment (of 1 percent of GDP), when interest rates are at the effective lower bound and when they are not. The dotted lines reflect the 90% confidence interval.

shown in Figure 7 are consistent with this negative 'supply-side' effect of public investment. Compared to the responses to the government consumption shock, where we found inflation to rise by more in the presence of the ELB than in the absence of the ELB, we find the reverse for the effects of a government investment shock. The more muted response of inflation to the investment shock at the ELB also translates into a less pronounced decline in the real interest rate as compared to the response of the real interest rate to a government consumption shock.

4.3 Robustness analysis

4.3.1 Changing the definition of the ELB proxy

Although the results presented in Figures 6 and 7 are consistent with conventional Keynesian theory, they depend on our definition of ELB spells. Different results may be obtained if an alternative definition of the ELB is used. In order to test whether our results are robust, we estimate the government consumption and investment multipliers for different definitions of the ELB.

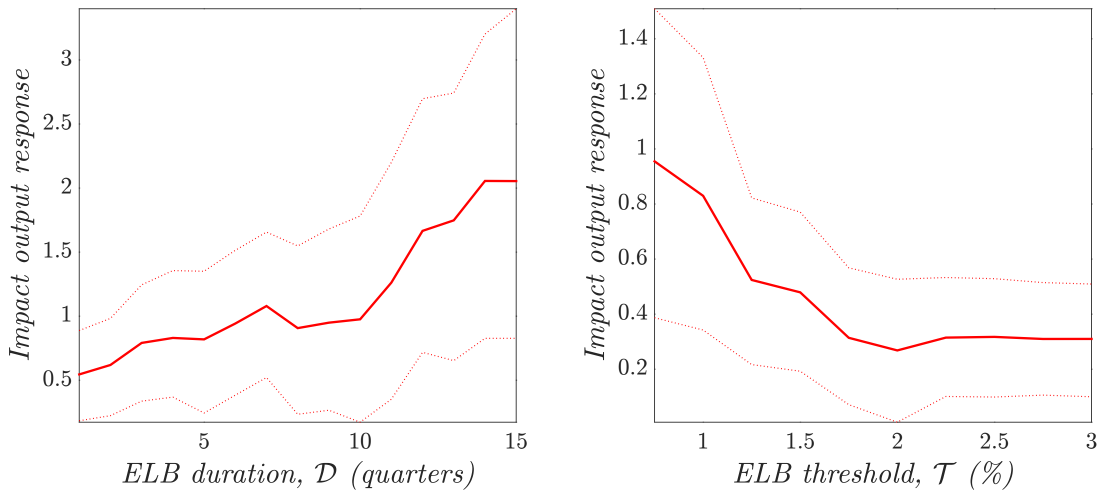
In particular, recall that ELB episodes were defined as periods during which the nominal interest rate is below $\mathcal{T}$ percent for at least $\mathcal{D}$ consecutive quarters, with $\mathcal{T} = 1$ and $\mathcal{D} = 4$, see (1). This section shows how altering either $\mathcal{D}$ or $\mathcal{T}$ affects the estimated impact multipliers and how the results relate to our theoretical benchmark. Throughout, we use the same model as before, as given by (3), and keep the number of lags fixed at $K = M = 5$ for the model with only government consumption, and $K = M = 6$ for the model with both government consumption and government investment. In doing so, we iterate only along one dimension which allows us to isolate the effects of either the ELB duration or the ELB threshold.

Figure 8 plots the estimated government consumption multipliers as a function of either $\mathcal{D}$ or $\mathcal{T}$. In the left-hand side panel, the threshold value for the nominal interest rate is kept at $\mathcal{T} = 1$ percent while the duration of the ELB, $\mathcal{D} \in [1, 15]$, varies along the horizontal axis. The results suggest that government consumption shocks have positive output responses on impact, with the responses being higher for more prolonged ELB episodes, i.e. for higher values of $\mathcal{D}$. These results are in line with our theoretical benchmark (see Figure 3): when the period during which monetary policy is constrained is extended, the real interest rate effect described earlier becomes more persistent, which translates into stronger output effects of fiscal policy. Indeed, whereas the impact multiplier under our baseline assumption of $\mathcal{D} = 4$ is about 0.8, it rises to 2 under the assumption that the ELB lasts for $\mathcal{D} = 15$ quarters.

The right-hand side panel of Figure 8 shows estimates of the impact multiplier under different assumptions for the threshold value for the nominal interest rate, $\mathcal{T}$, while keeping the ELB duration fixed at $\mathcal{D} = 4$ consecutive quarters. The results suggest that the impact multiplier falls for higher threshold values, which is again consistent with our theoretical benchmark (see Figure 4): the greater is the scope for the interest rate to adjust in response to shocks, the stronger will be the monetary offset of fiscal shocks, and therefore the smaller will be the response of output to an increase in government spending. With $\mathcal{T}$ sufficiently high, we obtain impact multipliers that are essentially the same as those found in the absence of a binding ELB.

Figure 9 shows the estimates of the government investment multipliers as a function of

Figure 8: Impact government consumption multipliers and the role of $\mathcal{D}$ and $\mathcal{T}$



Note: The ELB proxy refers to episodes when the nominal policy rate is below $\mathcal{T}$ percent for at least $\mathcal{D}$ consecutive quarters, see (1). In the left-hand side panel, we keep the threshold fixed at $\mathcal{T} = 1$ percent; in the right-hand side panel, we keep the ELB duration fixed at $\mathcal{D} = 4$ quarters. The dotted lines reflect the 90% confidence interval.

either $\mathcal{D}$ or $\mathcal{T}$. The figure suggest that extending the ELB duration and/or limiting the scope for interest rate adjustments amplifies (on average) the fiscal multiplier on impact. However, an important caveat is that extending the assumed duration of the ELB, or reducing the threshold value for the nominal interest rate, unavoidably reduces the number of observations and increases the uncertainty surrounding the point estimates.[9]

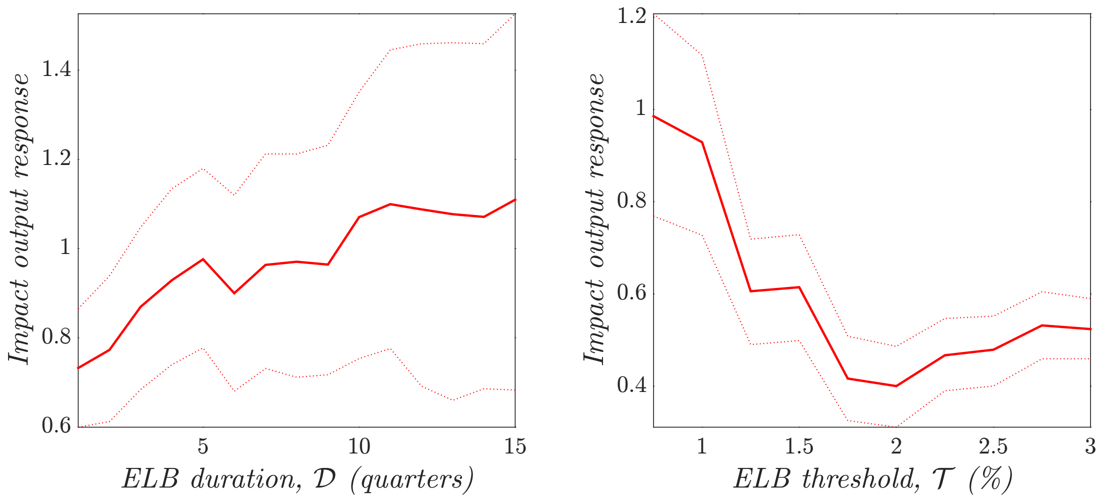
4.3.2 Excluding the euro area countries from the sample

As discussed in Section 3, the inclusion of euro area countries in our sample might bias our estimates, as our identification strategy might mistakenly capture the influence of the monetary regime rather than that of the ELB on the effects of fiscal policy. In particular, as shown in Figure 5, the euro area countries included in our sample experienced ELB spells only when they were part of the euro area, i.e. after 1999, during which they faced a quasi fixed exchange rate regime.[10] Before EMU, when these countries faced a more flexible exchange rate regime, interest rates were not at the ELB in these countries. So there is an identification

[9]For instance, at $\mathcal{D} = 15$, the only countries that remain in the sample are Japan, the UK and the US.

[10]Since the euro is free to fluctuate against other currencies, euro area countries only face a fixed exchange rate within the euro area. Hence the term *quasi* fixed exchange rate regime.

Figure 9: Impact government investment multipliers and the role of $\mathcal{D}$ and $\mathcal{T}$



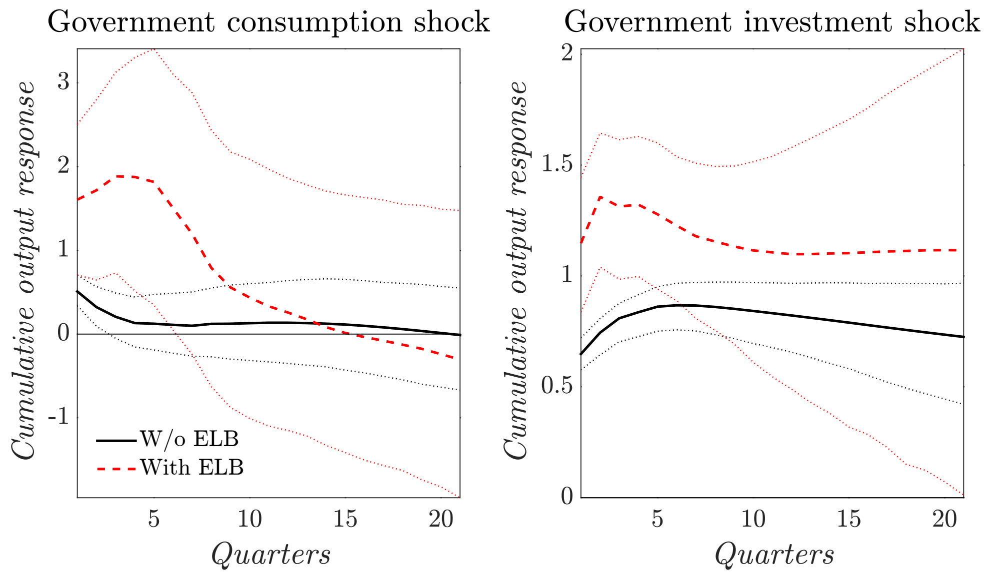
Note: The ELB proxy refers to episodes when the nominal policy rate is below $\mathcal{T}$ percent for at least $\mathcal{D}$ consecutive quarters, see (1). In the left-hand side panel, we keep the threshold fixed at $\mathcal{T} = 1$ percent; in the right-hand side panel, we keep the ELB duration fixed at $\mathcal{D} = 4$ quarters. The dotted lines reflect the 90% confidence interval.

problem, since the effects of a fixed exchange rate regime on the fiscal multiplier have been found to be similar to the effects of the ELB (Corsetti et al., 2012; Ilzetzki et al., 2013). Particularly, the monetary authority under a fixed exchange rate regime will not counteract an expansionary fiscal shock by raising the interest rate, since it is committed to protect the exchange rate peg. Therefore, the crowding-out effects of fiscal policy are likely to be weaker under fixed exchange rates than under flexible exchange rates, since the interest rate is less responsive under the former regime.

In order to control for the possible effects of a change in the monetary regime, we exclude the members of the euro area, except Germany, from the sample in the next robustness exercise. We keep Germany in the sample, because, given Germany's relatively large size within the euro area, fiscal shocks in Germany are probably large enough to provoke a change in the ECB's policy rate provided the ELB is not binding. For this smaller sample of countries, and using the model specified by (3) and the ELB definition specified by (1), we obtain estimates for the government consumption and investment multipliers.

The results, as shown in Figure 10, suggest that our main findings remain intact after excluding euro area countries (except for Germany) from the sample. As before, we find that

Figure 10: Impulse responses of GDP to a fiscal shock using a smaller country sample



Note: The results show the discounted cumulative responses of GDP to an increase in government consumption and investment (of 1 per cent of GDP), when interest rates are at the effective lower bound and when they are not. The dotted lines reflect the 90% confidence interval. The results are generated using a smaller sample of countries, which excludes all euro area countries, except for Germany.

the response of GDP to both a government consumption shock and government investment shock is significantly stronger in the presence of a binding ELB (dashed lines) than in its absence (solid lines). Moreover, using this smaller sample of countries we find a larger peak of the cumulative multiplier when the ELB is present: the cumulative government consumption (investment) multiplier peaks at 1.88 (1.35), compared to 1.7 (1.03) for the full sample of countries.

4.3.3 Controlling for the business cycle

As a final robustness check, we add an additional constraint on the *output gap* to the definition of the ELB, defined in (1), in order to control for the potential effects of changes in the business cycle on the size of the multiplier. As shown by Auerbach and Gorodnichenko (2012b), among others, the effects of fiscal policy may vary depending on the state of the economy. During a crisis, for instance, many households and firms might be credit constrained due to elevated risk premia and borrowing costs, implying that their marginal propensity to consume is relatively high. As a consequence, the fiscal multiplier is likely to be higher in times of recession than in times of more benign economic conditions. As reported by Auerbach and Gorodnichenko, multipliers are well above unity during recessions, yet are found to be between 0 and 0.5 during expansions.

One could imagine that ELB episodes typically take place when the economy faces a substantial amount of slack, as monetary policy responds to slack by actively reducing the interest rate. Therefore, a potential identification issue arises since both the ELB and economic slack are expected to push the multiplier in the same direction. To solve this issue, we now define ELB episodes as those during which *the nominal interest rate is below 1 percent for at least 4 consecutive quarters and the output gap is positive for at least 3 consecutive quarters*. Letting $OG_{n,t}$ denote a measure of the output gap, the restrictions on the ELB dummy, $D_{n,t}$, can then be changed accordingly:

$$D_{n,t} = \begin{cases} 1 & \text{if } \{R_{n,t-s} | s = 0,1,2,3\} < 1\% \text{ and } \{OG_{n,t-s} | s = 0,1,2\} > 0, \\ 0 & \text{otherwise.} \end{cases} \tag{4}$$

Using this modified definition of the ELB proxy, the effects of the ELB on the size of the multiplier can be estimated without being contaminated by the effects of economic slack.

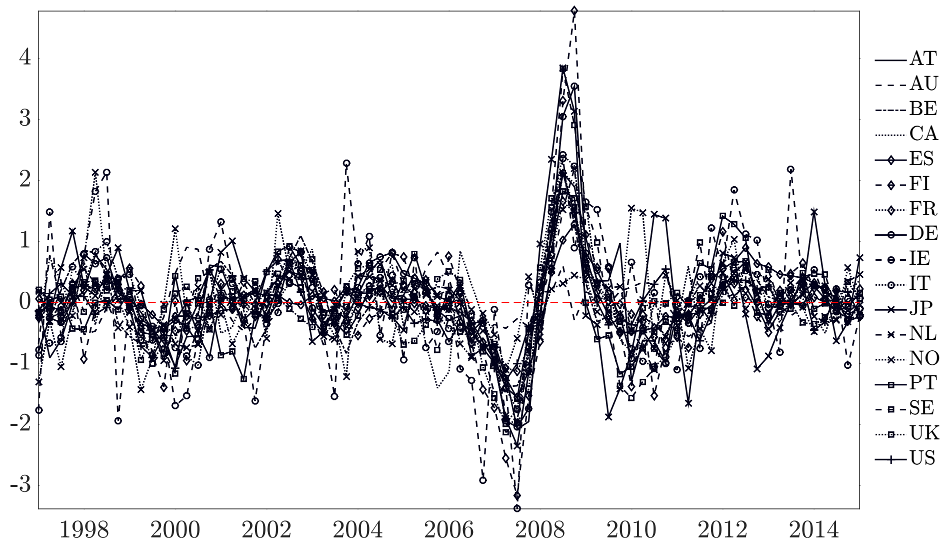
The top panel of Figure 11 shows the output gap for our full sample of advanced economies during 1960Q1-2015Q1, along with the output gap threshold used in the modified definition of the ELB proxy (horizontal dashed line). We calculate the output gap as the percentage deviation of real GDP from its trend. Following Auerbach and Gorodnichenko (2012a), we obtain the latter by applying a two-year moving average Hodrick-Prescott filter, with a smoothing parameter of $\lambda = 10,000$. The reason for using the moving average HP filtered trend is to capture possible time variation in the trend across countries.[11]

Compared to Figure 5, Figure 11 suggests that prolonged spells of low interest rates

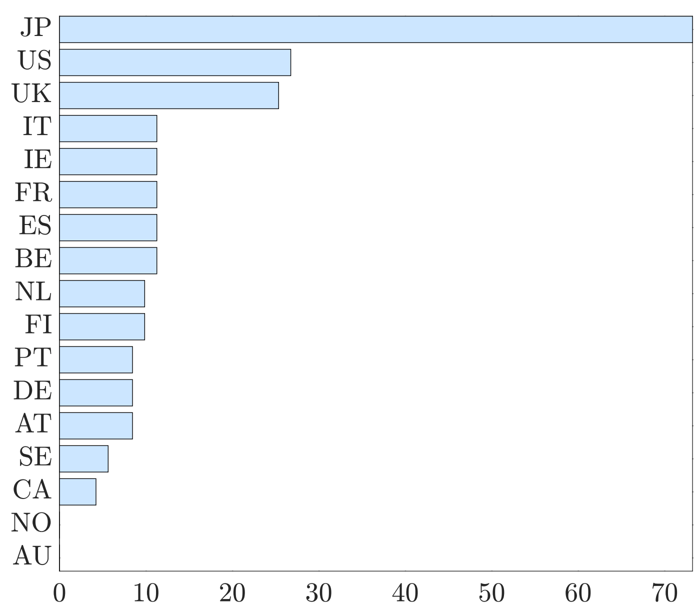
[11] As discussed in Auerbach and Gorodnichenko (2012a), the large smoothing parameter is used to prevent the trend from following cyclical fluctuations too much. Our results are, however, robust to alternative values for the smoothing parameter, such as $\lambda = 1,600$, which is more commonly used for quarterly data. Results are available on request.

Figure 11: Output gap and ELB incidence

(a) Output gap (%)

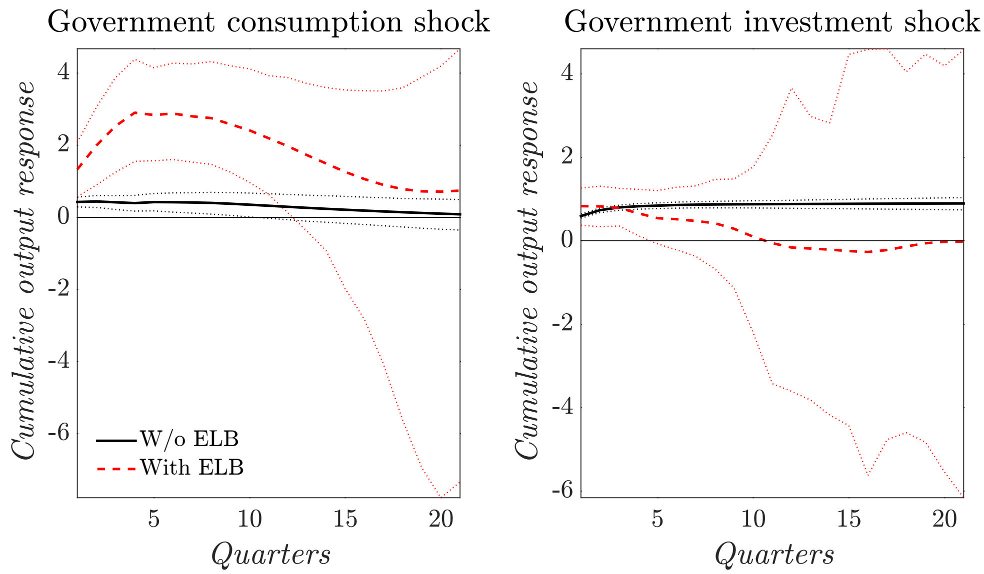


(b) Fraction of time spent at ELB (%) under additional output gap restriction, 1997Q1-2015Q1



Note: Countries are assumed to face the ELB when the policy rate set by the central bank is below 1 percent for at least 4 consecutive quarters and the output gap is positive for at least 3 consecutive quarters, see (4). *Source*: Datastream, OECD Quarterly National Accounts Database and own calculations.

Figure 12: Impulse responses of GDP to a fiscal shock with output gap restriction



Note: The results show the discounted cumulative responses of GDP to an increase in government consumption and investment (of 1 percent of GDP), when interest rates are at the effective lower bound and when they are not. The dotted lines reflect the 90% confidence interval. The ELB is defined according to Equation (4).

did indeed coincide with negative output gaps on some occasions. As a consequence, the fraction of time spent at the ELB according to the new definition of the ELB proxy is, for all countries, less than under the old definition of the ELB proxy, which does not include the positive output gap restriction (see bottom panel of Figure 11). In particular, under the old definition of the ELB, we observed a total of 204 instances during which $D_{n,t} = 1$; under the modified definition of the ELB, this number drops to 168.

The estimates for the government consumption and investment multiplier, while controlling for the effects of the business cycle using the modified definition of the ELB (4), are shown in Figure 12. The figure suggests that the response of GDP to a government consumption shock is still significantly higher in the presence of a binding ELB than in its absence (left-hand side panel). Moreover, we find a maximum cumulative multiplier of 2.9, which is substantially larger than under the baseline specification where we did not control for the business cycle. The estimated effects of the government investment shock are, however, no longer significant at the ELB (right-hand side panel), which is most likely due to the limited number of remaining observations after applying the modified ELB proxy.

5 Conclusion

Nowadays, fiscal policy is often called upon to support monetary policy, which is severely constrained due to interest rates being at their effective lower bound. Although theoretical analyses suggest that fiscal policy might be more effective when the economy faces the ELB than under normal circumstances, there is only limited evidence in support of this prediction.

In this paper, we estimate the effects of government consumption and investment shocks during prolonged episodes of low interest rates, which we consider as a proxy for the effective lower bound. Using a panel VAR model for 17 advanced countries, in which we include real government spending, output, inflation, and the real interest rate, we find that both the cumulative government consumption and investment multipliers are significantly higher (and exceeding unity) when interest rates are persistently low. These results are robust for using different threshold values for the nominal interest rate or the length of the period with low interest rates to proxy the ELB. Also, excluding the euro area countries from the sample and taking into account the business cycle in defining the proxy for the ELB does not affect our main conclusions. Our results therefore support pleas by several central bankers and other policymakers to give fiscal policy a more important role in stabilizing the economy, provided fiscal policy sustainability allows doing so.

References

Albertini, J., Poirier, A., and Roulleau-Pasdeloup, J. (2014). The composition of government spending and the multiplier at the zero lower bound. *Economics Letters*, 122(1):31–35.

Auerbach, A. J. and Gorodnichenko, Y. (2012a). Fiscal multipliers in recession and expansion. In *Fiscal Policy after the Financial crisis*, pages 63–98. University of Chicago press.

Auerbach, A. J. and Gorodnichenko, Y. (2012b). Measuring the output responses to fiscal policy. *American Economic Journal: Economic Policy*, 4(2):1–27.

Baxter, M. and King, R. G. (1993). Fiscal policy in general equilibrium. *The American Economic Review*, pages 315–334.

Beetsma, R., Giuliodori, M., and Klaassen, F. (2008). The effects of public spending shocks on trade balances and budget deficits in the European Union. *Journal of the European Economic Association*, 6(2-3):414–423.

Bernardini, M. and Peersman, G. (2015). Private debt overhang and the government spending multiplier: Evidence for the United States. CESifo Working Paper Series 5284, CESifo.

Blanchard, O. and Perotti, R. (2002). An empirical characterization of the dynamic effects of changes in government spending and taxes on output. *Quarterly Journal of Economics*, 117:1329–1368.

Blanchard, O. J. and Quah, D. (1993). The dynamic effects of aggregate demand and supply disturbances. *The American Economic Review*, 83(3):653–658.

Blinder, A., Ehrman, M., de Haan, J., and Jansen, D. (2017). Necessity as the mother of invention: Monetary policy after the crisis. *Economic Policy (forthcoming)*.

Bouakez, H., Guillard, M., and Roulleau-Pasdeloup, J. (2017). Public investment, time to build, and the zero lower bound. *Review of Economic Dynamics (in press)*.

Christiano, L., Eichenbaum, M., and Rebelo, S. (2011). When is the government spending multiplier large? *Journal of Political Economy*, 119(1):78–121.

Coenen, G., Erceg, C. J., Freedman, C., Furceri, D., Kumhof, M., Lalonde, R., Laxton, D., Lindé, J., Mourougane, A., Muir, D., Mursula, S., Resende, C. D., Roberts, J., Roeger, W., Snudden, S., Trabandt, M., and in't Veld, J. (2012). Effects of fiscal stimulus in structural models. *American Economic Journal: Macroeconomics*, 4(1):22–68.

Corsetti, G., Meier, A., and Müller, G. J. (2012). What determines government spending multipliers? *Economic Policy*, 27(72):521–565.

Crafts, N. and Mills, T. C. (2013). Fiscal policy in a depressed economy: Was there a 'free lunch' in 1930s' Britain? CEPR Discussion Papers 9273, CEPR.

De Castro, F. and de Cos, P. H. (2008). The economic effects of fiscal policy: The case of Spain. *Journal of Macroeconomics*, 30(3):1005–1028.

Draghi, M. (2014). Unemployment in the euro area, speech by mario draghi, president of the ecb. In *Annual central bank symposium in Jackson Hole*, volume 22.

Eggertsson, G. B. (2011). What fiscal policy is effective at zero interest rates? In *NBER Macroeconomics Annual 2010, Volume 25*, pages 59–112. University of Chicago Press.

Erceg, C. and Lindé, J. (2014). Is there a fiscal free lunch in a liquidity trap? *Journal of the European Economic Association*, 12(1):73–107.

Fatás, A. and Mihov, I. (2001). The effects of fiscal policy on consumption and employment: Theory and evidence. Discussion Paper 2760, CEPR.

Fischer, S. (2016). Longer-term challenges for the us economy: a speech at" a conversation with stanley fischer," sponsored by the council on foreign relations, new york, new york, november 21, 2016. Technical report.

Guerrieri, L. and Iacoviello, M. (2015). Occbin: A toolkit for solving dynamic models with occasionally binding constraints easily. *Journal of Monetary Economics*, 70:22–38.

Hall, R. E. (2009). By how much does GDP rise if the government buys more output? NBER Working Paper 15496, NBER.

Hebous, S. (2011). The effects of discretionary fiscal policy on macroeconomic aggregates: A reappraisal. *Journal of Economic Surveys*, 25(4):674–707.

Ilzetzki, E., Mendoza, E. G., and Végh, C. A. (2013). How big (small?) are fiscal multipliers? *Journal of Monetary Economics*, 60(2):239–254.

Leeper, E. M., Walker, T. B., and Yang, S.-C. S. (2010). Government investment and fiscal stimulus. *Journal of Monetary Economics*, 57(8):1000–1012.

Miyamoto, W., Nguyen, T. L., and Sergeyev, D. (2016). Government spending multipliers under the zero lower bound: Evidence from Japan. CEPR Discussion Paper DP11633, CEPR.

Morita, H. (2015). Japanese fiscal policy under the zero lower bound. *Economic Review*, 57(2):324–344.

Mountford, A. and Uhlig, H. (2009). What are the effects of fiscal policy shocks? *Journal of applied econometrics*, 24(6):960–992.

Perotti, R. (2008). In search of the transmission mechanism of fiscal policy. In Acemoglu, D., Rogoff, K., and Woodford, M., editors, *NBER Macroeconomics Annual*, volume 22, pages 169–226. University of Chicago Press.

Qazizada, W. and Stockhammer, E. (2015). Government spending multipliers in contraction and expansion. *International Review of Applied Economics*, 29(2):238–258.

Ramey, V. A. (2011). Identifying government spending shocks: It's all in the timing. *The Quarterly Journal of Economics*, 126(1):1–50.

Ramey, V. A. and Zubairy, S. (2014). Government spending multipliers in good times and in bad: Evidence from US historical data. NBER Working Paper 20719, NBER.

Stock, J. H. and Watson, M. W. (2001). Vector autoregressions. *The Journal of Economic Perspectives*, 15(4):101–115.

Taylor, J. B. (1993). Discretion versus policy rules in practice. In *Carnegie-Rochester conference series on public policy*, volume 39, pages 195–214. Elsevier.

Uhlig, H. (2010). Some fiscal calculus. *The American Economic Review*, 100(2):30–34.

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

A Building blocks of the New Keynesian model

A.1 Household preferences

In each period t, a representative household chooses consumption, c_t, hours worked, h_t, holdings of nominal, one-period bonds, B_t, and investment, i_t, in real private capital, k_t, in order to maximize expected life-time utility, which is given by

$$E_t \sum_{t=0}^{\infty} \beta^t z_{D,t} \left[\frac{\left(c_t - \omega c_{t-1}\right)^{1-\sigma}}{1-\sigma} - \frac{h_t^{1+\varphi}}{1+\varphi} \right], \tag{5}$$

where $\omega \geq 0$ measures the degree of habit formation in consumption, $\beta \in (0,1)$ is the discount factor, $1/\sigma$ ($\sigma > 0$) the elasticity of intertemporal substitution and $1/\varphi$ ($\varphi > 0$) the Frisch elasticity of labor supply. The variable $z_{D,t}$ represents a preference shock whose dynamics are captured by a stationary AR(1) process. This preference shock is used to simulate an increase in the household's desire to save that takes the economy to the effective lower bound. A similar method is used by Christiano et al. (2011).

The household pays real lump-sum taxes, τ_t, to the government, and receives labor income, $W_t h_t$ with W_t the nominal wage rate, and profits, $\mathcal{P}_t$, from intermediate goods firms which the household owns. Let P_t be the aggregate price index, r_k the real return on capital, and R_t the (risk-free) nominal interest rate. The household's budget constraint in real terms is then given by

$$c_t + \frac{B_t}{P_t} + i_t + \Gamma\left(i_t, k_{t-1}\right) + \tau_t = \frac{W_t}{P_t} h_t + \frac{R_{t-1}}{P_t} B_{t-1} + r_{k,t} k_{t-1} + \mathcal{P}_t. \tag{6}$$

$\Gamma\left(\cdot\right)$ represents the investment-adjustment cost function, with $\Gamma\left(1\right) = \Gamma'\left(1\right) = 0$ and $\Gamma''\left(1\right) > 0$, and which has the following functional form:

$$\Gamma\left(i_t, k_{t-1}\right) = \frac{\gamma}{2} \left(\frac{i_t}{k_{t-1}} - \delta \right)^2 k_{t-1}. \tag{7}$$

Private capital evolves according to

$$k_t = (1-\delta)\,k_{t-1} + i_t, \tag{8}$$

where $\delta \in [0,1]$ denotes the depreciation rate of private capital.

Subject to the budget constraint (6), the investment adjustment cost function (7), the law of motion for private capital (8), and an appropriate transversality condition, and taking prices, the wage rate, taxes, asset prices and initial bond holdings as given, the household maximizes the objective function (5), which yields the following first-order conditions:

$$\lambda_t = z_{D,t}\left(c_t - \omega c_{t-1}\right)^{-\sigma} - \beta E_t\left[z_{D,t+1}\omega\left(c_{t+1} - \omega c_t\right)^{-\sigma}\right], \tag{9}$$

$$h_t^{\varphi} = \lambda_t w_t, \tag{10}$$

$$\lambda_t = \beta E_t\left[\lambda_{t+1}\frac{R_t}{\pi_{t+1}}\right], \tag{11}$$

$$q_t = 1 + \gamma\left(\frac{i_t}{k_{t-1}} - \delta\right), \tag{12}$$

$$q_t = \beta E_t\left\{\frac{\lambda_{t+1}}{\lambda_t}\left[r_{k,t+1} + q_{t+1}(1-\delta) - \frac{\gamma}{2}\left(\frac{i_{t+1}}{k_t} - \delta\right)^2 - \gamma\left(\frac{i_{t+1}}{k_t} - \delta\right)\frac{i_{t+1}}{k_t}\right]\right\}, \tag{13}$$

where $\pi_t \equiv P_t/P_{t-1}$ denotes gross inflation and $w_t \equiv W_t/P_t$ the real wage rate. λ_t and ξ_t are the Lagrange multipliers corresponding to (6) and (8). Together, they define Tobin's Q as $q_t \equiv \xi_t/\lambda_t$.

Household consumption c_t is a composite of intermediate goods, $c_t(j)$ with $j \in [0,1]$ a firm-specific index, which are aggregated according to the following CES technology:

$$c_t = \left(\int_0^1 c_t(j)^{\frac{\epsilon-1}{\epsilon}}\,dj\right)^{\frac{\epsilon}{\epsilon-1}},$$

where $\epsilon > 1$ measures the elasticity of substitution between intermediate goods. Maximizing c_t, subject to an appropriate expenditure constraint and taking intermediate goods prices, $P_t(j)$, as given, yields the following demand schedule for a generic good $c_t(j)$ and the aggregate price index P_t:

$$c_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\epsilon} c_t, \qquad P_t = \left(\int_0^1 P_t(j)^{1-\epsilon}\, dj\right)^{\frac{1}{1-\epsilon}}. \tag{14}$$

The demand schedules for government consumption and private investment are described analogously.

A.2 Firms

Intermediate goods, $y_t(j)$, are produced by firm j using the following technology:

$$y_t(j) = k_{t-1}(j)^{\alpha} h_t(j)^{1-\alpha} k_{g,t-1}^{\alpha_g}, \tag{15}$$

where $k_{g,t}$ denotes public capital and $\alpha, \alpha_g \in [0,1]$ measure the output elasticity with respect to private and public capital. The firm aims to minimize its total real costs, subject to the production function (15), while taking the real wage rate, w_t, and the real cost of capital, $r_{k,t}$, as given. This yields the following equilibrium demand conditions for labor and private capital:

$$w_t = (1-\alpha)\frac{y_t(j)}{h_t(j)} mc_t, \qquad r_{k,t} = \alpha \frac{y_t(j)}{k_{t-1}(j)} mc_t, \tag{16}$$

where real marginal costs, mc_t, are denoted by

$$mc_t = w_t^{1-\alpha} r_{k,t}^{\alpha} k_{g,t-1}^{-\alpha_g} \alpha^{-\alpha} (1-\alpha)^{\alpha-1}. \tag{17}$$

Intermediate goods firms set prices with the aim of maximizing the discounted sum of current and future profits, conditional on the probability of non-price adjustment, which is governed by the parameter $\theta \in (0,1)$:

$$E_t \sum_{k=0}^{\infty} \theta^k \mathcal{Q}_{t,t+k} \left(\overline{P}_t y_{t,t+k}(j) - W_{t+k} h_{t,t+k}(j) - P_{t+k} r_{k,t+k} k_{t,t+k-1}(j)\right),$$

where $\overline{P}_t$ is the optimal reset price[12] and where $\mathcal{Q}_{t,t+k} \equiv \beta^k \left(c_{t+k}/c_t\right)^{-\sigma} \pi_{t+k}^{-1}$ is the k-step ahead equilibrium pricing kernel. Profits are distributed as dividends to the households. Subject to the demand schedule (14), the production technology (15), and the optimal demand conditions for labor and private capital (16), profit maximization leads to the following optimal reset price:

$$\overline{P}_t = \frac{\epsilon}{\epsilon - 1} \frac{E_t \sum_{k=0}^{\infty} \left(\theta\beta\right)^k P_{t+k}^{\epsilon} c_{t+k}^{-\sigma} y_{t+k} mc_{t+k}}{E_t \sum_{k=0}^{\infty} \left(\theta\beta\right)^k P_{t+k}^{\epsilon-1} c_{t+k}^{-\sigma} y_{t+k}}. \tag{18}$$

A.3 Public sector

The government levies real lump-sum taxes, τ_t, to cover public expenditures, which consists of public consumption, g_t, and investment, $i_{g,t}$:

$$\tau_t = g_t + i_{g,t}. \tag{19}$$

Public capital, investment and consumption evolve according to

$$k_{g,t} = \left(1 - \delta_g\right) k_{g,t-1} + i_{g,t}, \quad \delta_g \in [0, 1], \tag{20}$$

$$i_{g,t} = \rho_{ig} i_{g,t-1} + \varepsilon_{ig,t}, \quad \varepsilon_{ig,t} \sim \mathcal{N}\left(0, \sigma_{ig}^2\right), \tag{21}$$

$$g_t = \rho_g g_{t-1} + \varepsilon_{g,t}, \quad \varepsilon_{g,t} \sim \mathcal{N}\left(0, \sigma_g^2\right). \tag{22}$$

Monetary policy is described by the following interest rate feedback rule:

$$R_t = \max\left(1 + \mathcal{T}, Z_t\right), \tag{23}$$

where

$$\frac{Z_t}{Z} = \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{y_t}{y}\right)^{\phi_y}, \quad \phi_\pi > 1, \quad \phi_y \geq 0. \tag{24}$$

[12] Due to symmetry among firms, we can ignore the j-index.

A.4 Market clearing

Aggregate output is defined as

$$y_t = \left(\int_0^1 y_t\left(j\right)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}}.$$

Using appropriate aggregators for output, labor and capital, the following goods and labor market clearing conditions can be derived:

$$y_t = c_t + g_t + i_t + i_{g,t}, \tag{25}$$

$$y_t = k_{t-1}^{\alpha} h_t^{1-\alpha} k_{g,t-1}^{\alpha_g} \Delta_t^{-1}, \tag{26}$$

where $\Delta_t \equiv \int_0^1 \left(P_t\left(j\right)/P_t\right)^{-\epsilon} dj$ is a measure of price dispersion.

A.5 Calibration

The parameters are calibrated based on a quarterly frequency of t. For most parameters, we use values that are commonly used in the literature. Table 1 provides an overview of the benchmark calibration.

With regards the output elasticity to public capital, governed by α_g, the literature offers little guidance due to a lack of consensus on the effects of public capital on productivity; see Leeper et al. (2010) for a discussion. Here, we follow Baxter and King (1993) and use $\alpha_g = 0.05$ as a benchmark. Importantly, we find that raising α_g strengthens the negative supply-side effects of a government investment shock, thereby reducing the government investment multiplier.

Table 1: Benchmark calibration

Parameter	Description	Value
ω	Degree of consumption habit	0.5
σ	Inverse of the elasticity of intertemporal substitution	1.5
φ	Inverse of the Frisch elasticity of labor supply	2
β	Discount factor	0.99
γ	Investment adjustment costs parameter	6
δ, δ_g	Depreciation rate of private and public capital	0.02
α	Output elasticity with respect to private capital	0.33
α_g	Output elasticity with respect to public capital	0.05
θ	Probability of non-price adjustment	0.75
ρ_D	First-order auto-correlation coefficient of preference shocks	0.9
ρ_g	First-order auto-correlation coefficient of public consumption	0.9
ρ_{ig}	First-order auto-correlation coefficient of public investment	0.9
ϕ_π	Monetary response to inflation	1.5
ϕ_y	Monetary response to output	0.25
g/y	Steady-state public consumption ratio	0.2
c/y	Steady-state private consumption ratio	0.6
i/y	Steady-state private investment ratio	0.15

Previous DNB Working Papers in 2017

No. 542 **Jasper de Jong, Marien Ferdinandusse and Josip Funda**, Public capital in the 21st century: As productive as ever?
No. 543 **Martijn Boermans and Sweder van Wijnbergen**, Contingent convertible bonds: Who invests in European CoCos?
No. 544 **Yakov Ben-Haim, Maria Demertzis and Jan Willem Van den End**, Fundamental uncertainty and unconventional monetary policy: an info-gap approach
No. 545 **Thorsten Beck and Steven Poelhekke**, Follow the money: Does the financial sector intermediate natural resource windfalls?
No. 546 **Lola Hernandez, Robbert-Jan 't Hoen and Juanita Raat**, Survey shortcuts? Evidence from a payment diary survey
No. 547 **Gosse Alserda, Jaap Bikker and Fieke van der Lecq**, X-efficiency and economies of scale in pension fund administration and investment
No. 548 **Ryan van Lamoen, Simona Mattheussens, and Martijn Dröes**, Quantitative easing and exuberance in government bond markets: Evidence from the ECB's expanded asset purchase program
No. 549 **David-Jan Jansen and Matthias Neuenkirch**, News consumption, political preferences, and accurate views on inflation
No. 550 **Maaike Diepstraten and Carin van der Cruijsen**, To stay or go? Consumer bank switching behaviour after government interventions
No. 551 **Dimitris Christelis, Dimitris Georgarakos, Tullio Jappelli, Luigi Pistaferri and Maarten van Rooij**, Asymmetric consumption effects of transitory income shocks
No. 552 **Dirk Gerritsen, Jacob Bikker and Mike Brandsen**, Bank switching and deposit rates: Evidence for crisis and non-crisis years
No. 553 **Svetlana Borovkova, Evgeny Garmaev, Philip Lammers and Jordi Rustige**, SenSR: A sentiment-based systemic risk indicator
No. 554 **Martijn Boermans and Rients Galema**, Pension funds' carbon footprint and investment trade-offs
No. 555 **Dirk Broeders, Kristy Jansen and Bas Werker**, Pension fund's illiquid assets allocation under liquidity and capital constraints
No. 556 **Dennis Bonam and Gavin Goy**, Home biased expectations and macroeconomic imbalances in a monetary union
No. 557 **Ron Berndsen and Ronald Heijmans**, Risk indicators for financial market infrastructure: from high frequency transaction data to a traffic light signal
No. 558 **Monique Timmermans, Ronald Heijmans and Hennie Daniels**, Cyclical patterns in risk indicators based on financial market infrastructure transaction data
No. 559 **Dirk Bezemer, Anna Samarina and Lu Zhang**, The shift in bank credit allocation: new data and new findings
No. 560 **Jacob Bikker and Tobias Vervliet**, Bank profitability and risk-taking under low interest rates
No. 561 **Dirk Broeders, Arco van Oord and David Rijsbergen**, Does it pay to pay performance fees? Empirical evidence from Dutch pension funds
No. 562 **Nikki Panjer, Leo de Haan and Jan Jacobs**, Is fiscal policy in the euro area Ricardian?
No. 563 **Carin van der Cruijsen**, Payments data: do consumers want to keep them in a safe or turn them into gold?
No. 564 **Gabriele Galati and Federica Teppa**, Heterogeneity in house price dynamics

DeNederlandscheBank

EUROSYSTEEM

De Nederlandsche Bank N.V.
Postbus 98, 1000 AB Amsterdam
020 524 91 11
dnb.nl