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A Fiscal Price Puzzle?

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The inflation response to government spending shocks: A fiscal price puzzle?☆

Peter L. Jørgensen[a], Søren H. Ravn[b,*]

[a] Department of Economics, Copenhagen Business School, Porcelænshaven 16A, 1st Floor, DK-2000 Frederiksberg, Denmark
[b] Department of Economics, University of Copenhagen, Øster Farimagsgade 5, Building 26, DK-1353 Copenhagen, Denmark

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ABSTRACT

Standard New Keynesian models predict that expansionary fiscal policy is inflationary. In contrast, this paper presents empirical evidence that prices do not increase in response to a positive government spending shock. Instead, the response of prices is flat or even negative. This finding is robust across a wide range of specifications of our Structural Vector Autoregression (SVAR) model and across different price indices. The puzzling response of prices is accompanied by an increase in output and private consumption, as found in most of the existing literature, as well as an increase in Total Factor Productivity. We show that the introduction of variable technology utilization can enable an otherwise standard New Keynesian model to account for our empirical findings. The model implies that the government spending multiplier is substantially *lower* when the economy is in a fundamental liquidity trap, as compared to normal times, in contrast to the predictions of standard New Keynesian models.

1. Introduction

The macroeconomic effects of changes in government spending have received widespread attention in the economics profession, not least since the onset of The Great Recession in 2007. Following the tradition of Blanchard and Perotti (2002), a large literature has employed Structural Vector Autoregressive (SVAR) models to characterize the empirical effects of government spending shocks on GDP, private consumption, and a range of other macroeconomic variables (e.g., Galí et al., 2007; Ramey, 2011). However, the response of inflation to government spending shocks has typically received limited attention in the empirical literature. Nonetheless, the conventional wisdom is that increases in government spending are inflationary. Indeed, this idea plays an important role in the transmission of fiscal policy shocks in several theoretical models, including the textbook New Keynesian model. A prominent example is the effectiveness of government spending shocks when the nominal interest rate is at the zero lower bound (ZLB). The finding of a

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* Corresponding author.
E-mail addresses: pljo.eco@cbs.dk (P.L. Jørgensen), soren.hove.ravn@econ.ku.dk (S.H. Ravn).
URLs: https://sites.google.com/view/peterlihnjorgensen (P.L. Jørgensen), https://www.sorenhoveravn.com (S.H. Ravn).

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Table 1
Empirical estimates of inflation response.

Response of prices/inflation	Fiscal policy study
Inflationary	Edelberg et al. (1999), Caldara and Kamps (2008), Ben Zeev and Pappa (2017) and Ferrara et al. (2021).
Disinflationary or insignificant	Fatas and Mihov (2001a), Fatas and Mihov (2001b), Canzoneri et al. (2002), Perotti (2005), Mountford and Uhlig (2009), Nakamura and Steinsson (2014), Dupor and Li (2015), Ricco et al. (2016) and D'Alessandro et al. (2019).
Not reported	Blanchard and Perotti (2002), Burnside et al. (2004), Galí et al. (2007) and Ramey (2011)

Notes: All studies use U.S. data, though Perotti (2005) also considers other OECD countries. Canova and Pappa (2007) report evidence from the US and from Euro Area countries and obtain mixed price responses. See also Table A.1 in Appendix A.

large fiscal multiplier under these circumstances relies entirely on the ability of higher government spending to drive up (expected) inflation and thus reduce the real interest rate (e.g., Christiano et al., 2011).

In this paper, we study the effects of government spending shocks on prices in the U.S. economy using an SVAR approach. Our main finding is that prices do not increase in response to a fiscal expansion. Instead, the response of prices is typically negative, though often not statistically significant. This finding emerges across a wide variety of specifications of our empirical model, different price indices, and identification strategies. The puzzling response of prices is accompanied by an increase in output and private consumption, as found in most of the existing literature (e.g., Blanchard and Perotti, 2002; and Galí et al., 2007), as well as an increase in Total Factor Productivity (TFP). We find that the introduction of variable technology utilization can enable an otherwise standard New Keynesian model to account for these empirical findings. The model implies that the government spending multiplier is substantially *lower* in a fundamental liquidity trap than in normal times, in contrast to the predictions of standard New Keynesian models.

Table 1 lists some of the existing evidence on the price response to government spending shocks that has been reported in the literature. Consistent with our findings, most studies have reported that the response of prices to expansionary fiscal shocks is either negative (e.g., Fatas and Mihov, 2001b or Mountford and Uhlig, 2009) or insignificant (e.g., Nakamura and Steinsson, 2014), contrary to conventional wisdom.[1] Perotti (2005) finds mixed evidence of the response of inflation across five OECD countries, including the US, but concludes that there is little evidence in support of the common perception that government spending shocks are inflationary.[2] Several prominent studies of fiscal policy do not consider the response of prices at all, and most of the authors who find evidence of a muted or negative price response do not attempt to provide a structural explanation for it.

Our empirical findings are hard to reconcile with traditional accounts of the transmission mechanism of fiscal policy. From a theoretical viewpoint, a flat or negative response of prices constitutes a puzzle for the textbook New Keynesian model. To provide a structural interpretation of our results, we therefore propose a version of the New Keynesian model featuring time-varying adoption of new technology into the production process, as in recent work by Anzoategui et al. (2019) and Bianchi et al. (2019). In our model, firms decide on the extent to which they utilize the available technology level. In response to an increase in government spending, firms find it optimal to raise the utilization rate of technology in order to meet the increase in aggregate demand, despite the costs associated with a higher utilization rate. An increase in technology utilization raises measured productivity, in line with the empirical evidence we present. Provided this mechanism is sufficiently powerful, it dominates the upward pressure on marginal costs stemming from higher wages, leading to a decline in marginal costs in equilibrium. Lower marginal costs pave the way for firms to reduce their prices, thus generating a decline in inflation. In response, the central bank reduces the nominal interest rate, in line with what we observe in our SVAR evidence, leading to a drop in the real interest rate. This, in turn, facilitates an increase in consumption.

The textbook version of the New Keynesian model typically features a negative comovement between inflation and private consumption conditional on a shock to government spending, but of the opposite sign than suggested by the data: inflation increases and consumption declines after a positive government spending shock. In our model, as in the basic New Keynesian model, combining a standard consumption Euler equation with a version of the Taylor rule for monetary policy results in a negative relationship between consumption and inflation. However, in our model, an increase in government spending shifts the economy down along this consolidated Euler equation, resulting in a *decline* in inflation and an *increase* in consumption, in line with the data. We provide an analytical characterization of the parameter requirements for our model to generate these findings, and show that a range of parameters always exists for which this is the case. We then augment the model with several realistic features, including

[1] Table A.1 in Appendix A extends Table 1 along several dimensions, including sample period, identification schemes, etc. As we discuss in Section 2.4, all studies reporting a positive price response to expansionary fiscal shocks have used some version of war dummies or defense news shocks to identify government spending shocks (see Edelberg et al., 1999; Caldara and Kamps, 2008; Ben Zeev and Pappa, 2017; Ferrara et al., 2021). Our results in Section 2.4 suggest that these studies may suffer from a weak instruments problem, as discussed by Ramey (2016).

[2] As seen in Table 1, some studies report the response of the price level, and others that of the inflation rate, but this cannot explain the different findings in the literature. While we use the price level in all our estimations, none of our findings depend on this choice.

capital formation, sticky wages, and consumption habits, and estimate the key parameters using impulse-response matching. We find that variable technology utilization is a necessary feature for the model to provide a good account—qualitatively as well as quantitatively—of the empirical effects of a shock to government spending.

Our results have implications for the broader fiscal policy debate. While government spending policy is typically believed—at least in the short run—to primarily affect the demand side of the economy (e.g. Blanchard and Perotti, 2002), our findings point to the existence of significant effects also on the supply side. The endogenous response of TFP increases the government spending multiplier without creating inflationary pressure in the economy. All else equal, this makes government spending more attractive as a policy tool—except when the nominal interest rate is at its zero lower bound or, more generally, when inflation falls short of its target. As we demonstrate in the final part of the paper, our model implies that the government spending multiplier is substantially *lower* in a fundamentally-driven ZLB episode than in normal times, contrary to the prediction of the textbook New Keynesian model. Intuitively, the negative response of (expected) inflation to a government spending shock increases the real interest rate in our model when the economy is at the ZLB. As a result, private consumption *declines* in response to the fiscal expansion, leading to a lower government spending multiplier.

1.1. Related literature

The response of consumption to government spending shocks has received widespread attention in the theoretical literature, with several authors proposing mechanisms to obtain an increase in consumption. However, most of these seem to hold little promise for producing a flat or negative response of inflation. For example, the introduction of rule-of-thumb households by Galí et al. (2007) drives up aggregate demand but has no direct effects on the supply side. Allowing for non-separable utility in consumption and leisure, as in Monacelli and Perotti (2008) and Bilbiie (2011), induces consumption and labor supply to increase in tandem, provided consumption and leisure are substitutes. However, as shown by Bilbiie (2011), the demand-side effects still dominate, leading to a rise in inflation.

In the New Keynesian model, there are essentially three ways to bring about a drop in inflation in response to a government spending shock: a drop in the wage rate, a drop in the markup, or an increase in productivity. A drop in the wage rate may be obtained in the presence of a sufficiently strong increase in labor supply in response to the reduction in permanent income associated with higher government spending (Baxter and King, 1993). However, our empirical evidence shows a clear increase in the wage rate. A countercyclical markup, on the other hand, is the hallmark of the so-called deep habits model of Ravn et al. (2006). Zubairy (2014) shows that a medium-scale DSGE model with deep habits in both private and public consumption delivers a drop in inflation and an increase in consumption in response to a fiscal spending shock. However, this approach cannot account for the increase in TFP observed in the data. These considerations lead us to focus on endogenous changes in the level of productivity as a more promising avenue for matching the empirical evidence.

We contribute to an emerging literature studying endogenous changes in productivity over the business cycle. We build directly on the work of Bianchi et al. (2019), who propose an endogenous growth model capturing both business-cycle fluctuations and long-term growth. In their model, endogenous variations in TFP can arise due to variable technology utilization or R&D investments in “knowledge capital”. At business-cycle frequencies, they find that variations in technology utilization account for the bulk of fluctuations in TFP, whereas the accumulation of knowledge capital is important for long-term growth. In related work, Anzoategui et al. (2019). find that most of the observed decline in TFP during the Great Recession can be attributed to endogenous factors, primarily a decline in the intensity of technology adoption. Moran and Queralto (2018) use a similar model to study the link between monetary policy shocks and endogenous movements in technology after establishing that a monetary expansion leads to an increase in TFP in the data. Okada (2020) documents that the introduction of endogenous technology into New Keynesian models resolves a number of empirical puzzles encountered in the literature. However, none of these papers study the connection between endogenous productivity and fiscal policy. In this respect, two existing studies are more closely related to our paper. Aghion et al. (2014) find that systematic, countercyclical fiscal policy can have positive long-term effects on productivity growth. To rationalize this finding, they devise a model in which countercyclical fiscal policy leads to a reduction in business-cycle volatility, which in turn facilitates investments in productivity-enhancing long-term projects, such as R&D investments. D’Alessandro et al. (2019) show that a business-cycle model with learning-by-doing can generate positive responses of private consumption, the real wage, and TFP and a negative inflation response to a government spending shock. As we discuss in Section 5, this mechanism may complement the one we propose, but is unlikely to be the main driver of our findings.[3]

Our findings are reminiscent of the so-called “price puzzle” of monetary policy (Sims, 1992). We confirm that our results do not suffer from common types of misspecification that have been proposed in this regard (notably, the drop in prices is confirmed when commodity prices are included in the VAR model). Finally, our results are also related to the puzzling behavior of the real exchange rate in connection with fiscal policy in open economies. Kim and Roubini (2008), Monacelli and Perotti (2010), and Ravn et al. (2012) all find that the real exchange rate depreciates in response to an expansionary government spending shock, i.e. that domestic prices decline relative to foreign (exchange-rate-adjusted) prices. Recently, Ferrara et al. (2021) have reported evidence of an exchange rate appreciation by combining a narrative identification strategy with a proxy-SVAR approach. They show that an open-economy real business cycle model can account for their findings.

[3] Mumtaz and Theodoridis (2020) employ a model featuring both productive government spending, learning-by-doing, and variable technology utilization to study the response of stock prices to government spending shocks. Their model also generates a drop in the general price level, but tracing out the relative importance of these various supply-side mechanisms is not straightforward.

The rest of the paper is structured as follows. We present our empirical results in Section 2. Our model of variable technology utilization is outlined in Section 3, while Section 4 is devoted to studying its properties analytically. In Section 5 we estimate an extended version of the model. We study the properties of the model at the Zero Lower Bound in Section 6, while Section 7 concludes.

2. Fiscal policy and the price level: empirical evidence

In this section, we set up a Structural VAR model for the U.S. economy to investigate the effects of government spending shocks on key macroeconomic variables. As a baseline, we use the forecast errors of government spending computed by Auerbach and Gorodnichenko (2012) to identify shocks to government spending. To check the robustness of our results, we consider a vast number of alternative specifications of our VAR model, as well as alternative identification schemes, including the standard Cholesky decomposition (see, e.g. Blanchard and Perotti, 2002).

We estimate the following quarterly VAR model on U.S. data:

$$\mathbf{X}_t = a_0 + a_1 t + a_2 t^2 + B^{-1} A(L)\mathbf{X}_{t-1} + B^{-1} e_t, \tag{1}$$

where $\mathbf{X}_t$ is the vector of endogenous variables, e_t is a vector of i.i.d. structural shocks with unit variance, $A(L)$ comprises the coefficients on the lagged endogenous variables, L is the lag operator, and B comprises the coefficients on the contemporaneous endogenous variables. We include linear and quadratic time trends, as in Blanchard and Perotti (2002). Following most of the literature, we use 4 lags as our baseline. We obtain the implied forecast errors of the survey-based forecasts of the growth rate of government spending from Auerbach and Gorodnichenko (2012). This series (denoted FE_t) is available starting in 1966:Q4. As our baseline, we end the sample in 2008:Q3, so as to avoid the period in which U.S. monetary policy was restricted by the ZLB on nominal interest rates (we include more recent data as a robustness check). We use the following variables in our analysis: Real government expenditure and investment (G_t), real GDP (Y_t), real private consumption (C_t), real net tax revenues (tax receipts less current transfers, interest payments and subsidies) (T_t), the real wage (W_t), the Personal Consumption Expenditures (PCE) price index (P_t), the nominal interest rate on 3-month Treasury Bills (R_t), and Total Factor Productivity (A_t). All variables except R_t are in logs, and the variables G_t, Y_t, C_t and T_t are measured in real per-capita terms. T_t is converted into real terms using the GDP deflator. We use the TFP measure of Fernald (2014).[4] Appendix B contains a detailed data description.

2.1. Baseline VAR model

Following the seminal contribution of Blanchard and Perotti (2002), much of the empirical literature on the effects of fiscal policy shocks have relied on a Cholesky decomposition to identify shocks to government spending. However, a common criticism of the Cholesky identification strategy is that changes in fiscal policy are—at least to some extent—anticipated by economic agents, as discussed by Ramey (2011), among others. In this case, it is not possible to recover a structural shock to fiscal policy using the identification strategy of Blanchard and Perotti (2002). To account for this, we consider an identification scheme that controls for fiscal foresight. Following Auerbach and Gorodnichenko (2012), we identify an unanticipated government spending shock as an innovation to the forecast error of the growth rate of government spending. The vector of endogenous variables is

$$\mathbf{X}_t = \begin{bmatrix} FE_t & G_t & Y_t & C_t & T_t & W_t & P_t & R_t & A_t \end{bmatrix}'.$$

In order to recover an unanticipated government spending shock from the estimated residuals $B^{-1}e_t$ in (1), we order FE_t first in the system. We then impose a lower triangular structure on the matrix B. This implies that forecast errors of government spending are assumed to be exogenous, i.e. they do not respond to any other variable within-quarter, but affect other variables within the same quarter. We order G_t immediately after FE_t, as in Auerbach and Gorodnichenko (2012), while the ordering of the remaining variables is such that real variables (with the exception of TFP) are determined before nominal ones.

Fig. 1 shows the impulse-response functions to a positive government spending shock normalized to 1 percent, along with 68 and 90 percent bootstrapped confidence bands, obtained using the delta method with 2000 replications. All responses are in percent, except for the interest rate response, which is in basis points. Following a fiscal expansion, output and consumption increase significantly and persistently, in line with most of the empirical literature. On the other hand, there is no evidence of an increase in prices. Instead, the price level declines by around 0.3 percent at the trough, though this drop is not statistically significant. The drop in the implied annualized inflation rate reaches almost 40 basis points at its trough six quarters after the shock. TFP increases significantly, in line with the evidence reported by Bachmann and Sims (2012) and D'Alessandro et al. (2019). The increase in the real wage is consistent with the evidence of Galí et al. (2007) and D'Alessandro et al. (2019). Finally, the short-term nominal interest rate drops by around 50 basis points, while tax revenues increase.

[4] We use the non-utilization-adjusted TFP measure as our baseline. Our results are robust to using the utilization-based measure instead.

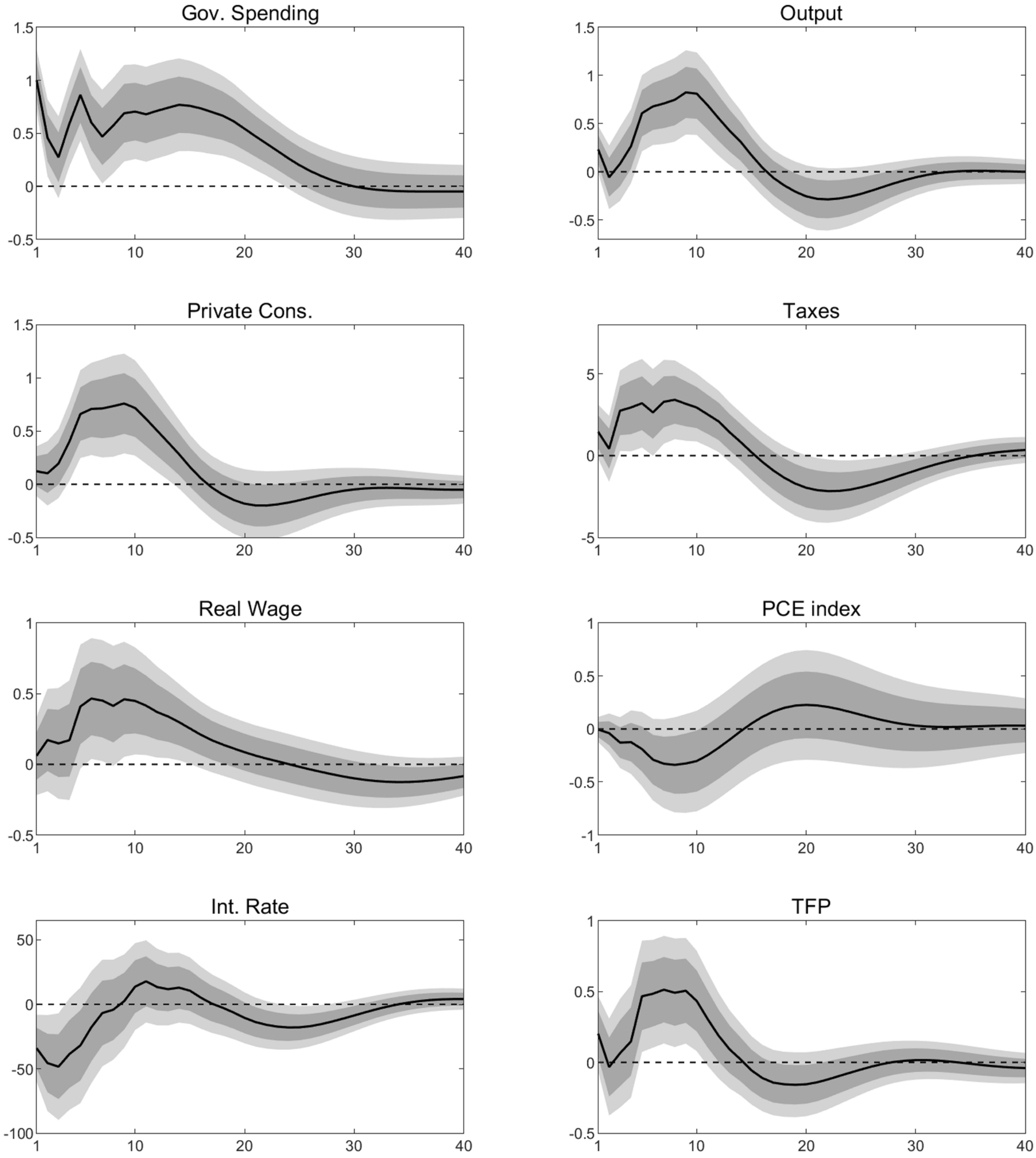

Fig. 1. The dynamic effects of a shock to government spending. Estimates obtained using the identification scheme based on forecast errors. The black line denotes the estimated response, while the gray areas represent the 68 percent confidence bands (dark gray) and the 90 percent confidence bands (light gray).

2.2. Cholesky decomposition

As a first robustness check, we consider a standard Cholesky identification strategy, following the tradition of Blanchard and Perotti (2002). Under the Cholesky identification scheme, the model contains the following variables:

$$\mathbf{X}_t = \begin{bmatrix} G_t & Y_t & C_t & T_t & W_t & P_t & R_t & A_t \end{bmatrix}'.$$

Since we no longer use the forecast error series, we start the sample in 1960:Q1. Following Blanchard and Perotti (2002), we now order G_t first in the system. Intuitively, this assumption is motivated by decision lags in fiscal policy. By the time policymakers realize that a shock has hit the economy and implement an appropriate policy response, at least one quarter would have passed.[5] Fig. 2 shows the impulse-response functions to a positive government spending shock under this alternative identification scheme. A positive spending shock generates a persistent increase in output, consumption, the real wage, and TFP, while the drop in prices is now strongly significant and very persistent.[6] Thus, all of our main findings are confirmed. The price level drops by around 0.3 percent at the peak. The implied annualized inflation rate drops by around 25 basis points at its trough two quarters after the shock. The short-term nominal interest rate drops by around 20 basis points, while tax revenues display an insignificant response.

2.3. Robustness

We consider a series of alternative specifications of our baseline VAR model with forecast error identification to check the robustness of our findings. Results are reported in Appendix C. Sims (1992) showed that prices increase on impact in response to a tightening of monetary policy; the so-called "price puzzle", but that this counterintuitive response could be alleviated by including commodity prices in the VAR model. Intuitively, commodity prices may contain signals of future price changes observed by central bankers, but not by an econometrician excluding commodity prices from her model. While this argument appears less appealing in the case of fiscal policy, we include a measure of commodity prices in the VAR model as a robustness check. Fig. C.1 shows that our results are confirmed when commodity prices are included.[7] In the same vein, some authors have argued that including inflation expectations in the VAR model can attenuate the price puzzle of monetary policy (see, e.g., Castelnuovo and Surico, 2010). In Fig. C.1 we also report the results obtained when we include the 1-year ahead inflation expectations from the Michigan Survey of Consumers. Again, this does not change any of our findings. Inflation expectations are found to decline in response to a government spending shock.

Fig. C.2 shows the impulse responses when the PCE price index is replaced by, respectively, the GDP deflator, the CPI index, or the core PCE index. All of these display negative or insignificant responses, while the responses of the remaining variables are largely unaffected. Likewise, we show in Appendix C that using an alternative measure of productivity (the log of real output per hour in the nonfarm sector) or excluding productivity from the VAR model altogether does not change our results.

We also test for subsample stability. We first extend the VAR model to include more recent data, including the ZLB period. To this end, we update the forecast errors of Auerbach and Gorodnichenko (2012) up to 2019:Q4 using data from the Survey of Professional Forecasters, and then run the VAR for the entire sample 1966:Q4–2019:Q4. The results are reported in Fig. C.3. Most of the responses are similar to our baseline sample, with the exception of the price level, which in this case displays a larger, more persistent, and statistically significant drop. In principle, comparing the results from the samples with and without the ZLB period might allow us to infer how the effects of government spending shocks differ at or away from the ZLB. However, the ZLB observations make up only 14 percent of the full sample, which therefore is dominated by non-ZLB dynamics, making such comparisons difficult. In Fig. C.3 we also show that our results are virtually identical if we estimate our VAR model over the full sample period from 1966:Q4 to 2019:Q4, replacing our baseline interest rate measure with the shadow interest rate from Wu and Xia (2016) from 1990:Q1 onwards (for which the shadow rate is available). Second, several authors have documented that the so-called "Great Moderation" in macroeconomic activity starting in the early to mid-1980's was characterized by a more active monetary policy which, in turn, could have changed the response of prices and other macroeconomic variables to government spending shocks (e.g., Lubik and Schorfheide, 2004; or Dupor and Li, 2015).[8] We therefore report in the left column of Fig. C.3 the impulse responses of the VAR model from a sample beginning in 1984:Q1.[9] Qualitatively, the results are largely in line with our previous findings. Quantitatively, however, many of the responses are less pronounced than in the full sample, and not statistically significant. In particular, the response of prices is virtually flat. A key driver of these findings is that the persistence of government spending shocks drops dramatically in the post-1984 period, as compared to the full sample, in line with the results of Bilbiie et al. (2008). Nonetheless, we still find no evidence of an increase in prices (see Fig. C.4).

Additional robustness checks reported in Appendix C include changing the lag length and dropping the quadratic time trend. The qualitative findings presented above are not altered by these changes. We have also verified that our VAR model of Section 2.1 does not suffer from non-fundamentalness, as discussed by Forni and Gambetti (2014), among others. Specifically, we regress the structural shocks from the VAR model on the lagged principal components of a large set of macroeconomic variables from the FRED-QD database (McCracken and Ng, 2020), and find that these do not Granger-cause the shocks.[10] In the same spirit, we have verified that our results do not change when we include the ratio of public debt to GDP in our VAR model, as proposed by Favero and Giavazzi (2007).

[5] This implies that the within-period elasticity of real government spending to a change in prices is assumed to be zero. In the absence of perfect indexation of government spending, this assumption may not be satisfied. Perotti (2005) suggests that the within-period elasticity of government spending to a change in prices might be as high as −0.5. We have verified that our findings are robust to this choice.

[6] The implied government spending multiplier on output can be found by multiplying the reported output response by the inverse of the sample average of the ratio of government spending to output, which is 0.25. This implies an impact multiplier of 1.07, not far from the multiplier of 0.84 found by Blanchard and Perotti (2002).

[7] The commodity price itself displays a decline in response to a government spending shock (not shown).

[8] A number of studies have documented a general disconnect between inflation and real economic activity in the US since 1984 (see, e.g., Atkeson and Ohanian, 2001). There is also evidence that the price puzzle of monetary policy is quantitatively smaller during this period (e.g., Castelnuovo and Surico, 2010).

[9] We have verified that our results are robust to the exact choice of starting date for this sample. Since this subsample is considerably shorter than our baseline sample, we reduce the number of lags proportionally in our VAR model for this subsample; from 4 to 2. We also exclude the quadratic trend. These choices are not crucial for our findings.

[10] We perform the test using between one and four lags of between one and five principal components. In all cases, the p-value for the F-test of joint significance is above 0.75, failing to reject the null hypothesis that the principal components do not predict the structural shocks.

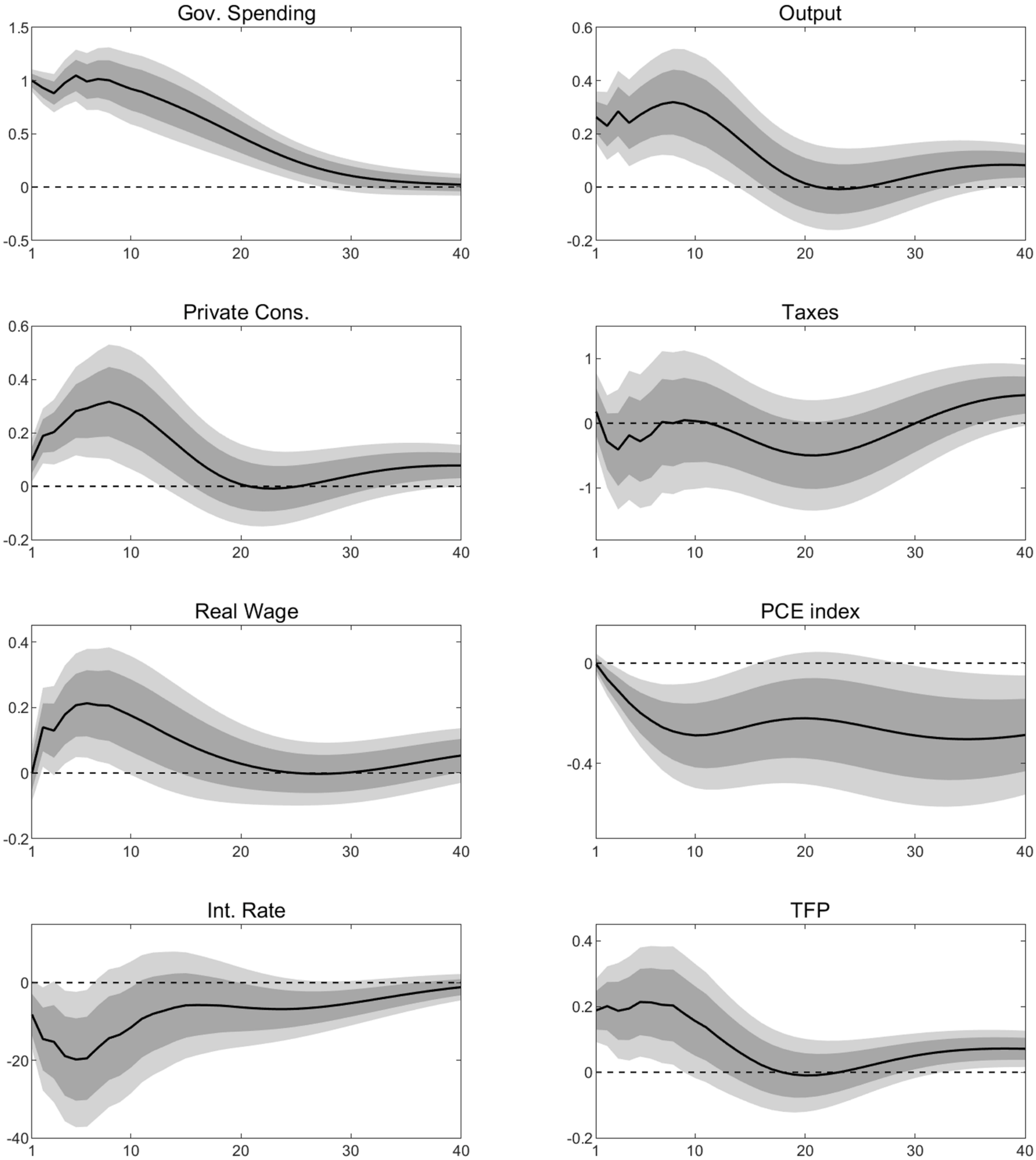

Fig. 2. The dynamic effects of a shock to government spending. Estimates obtained using the Cholesky identification scheme. The black line denotes the estimated response, while the gray areas represent the 68 percent confidence bands (dark gray) and the 90 percent confidence bands (light gray).

2.4. Alternative identification strategies

We finally consider two alternative identification schemes. First, as an alternative to the forecast-error approach of Auerbach and Gorodnichenko (2012), we use the defense news shocks constructed by Ramey (2011) to control for anticipated changes in government spending. Based on news sources, this data series seeks to identify surprise build-ups in U.S. military spending. We replace the forecast error, FE_t, with the news shocks variable, NS_t, in our VAR model. For this exercise, we extend the sample back to 1950:Q1 in order to include the Korean War, which has been shown to be important for the validity of the news shocks series as an instrument (Ramey, 2016). We still end the sample in 2008:Q3. The effects of an innovation to the news shock variable are reported in the left column of Fig. C.5 in Appendix C. We still find that prices tend to decline. However, we no longer observe an increase in consumption or the real wage—not unlike the findings in Ramey (2011). As we show in Table A.1 in Appendix A, the response of prices contrasts with existing studies relying on narrative defense news shocks, which have found that prices increase (e.g., Ben Zeev and Pappa, 2017 and Ferrara et al., 2021). As shown in Ramey (2016), however, the defense news shock series used in these studies are effectively weak instruments with very low statistical power.[11] The news shocks constitute a powerful instrument only when the Korean War is included, as in our sample (Ramey, 2016).

Second, we use sign restrictions to identify fiscal policy shocks. We use a VAR model featuring the same variables and sample period used for the Cholesky decomposition in Section 2.2. We identify a government spending shock as a shock that pushes up government spending and output on impact and in the following three quarters. We obtain 500,000 realizations that satisfy our identifying assumptions, and then report the median along with the 68 and 90 percent credible sets using the Bayesian approach of Mountford and Uhlig (2009). The results are shown in the right column of Fig. C.5. Using this approach, the price response is virtually flat, while the responses of the remaining variables are largely in line with our previous findings. Altogether, the evidence reported in Fig. C.5 confirms the puzzling result that government spending shocks are, if anything, disinflationary.

3. The model

To explain our empirical findings, we first consider a version of the baseline New Keynesian model without capital, as in Galí (2015). A representative household works, saves, consumes, and owns the firms in the economy. The production side consists of an intermediate goods sector operating under imperfect competition and subject to price rigidities, and a perfectly competitive final goods sector. A central bank conducts monetary policy, and a fiscal authority makes decisions about changes in government spending. A key feature of the model is the presence of variable utilization of the available technology level, as in Bianchi et al. (2019).[12]

3.1. The household

The representative household maximizes expected discounted lifetime utility $E_0 \sum_{t=0}^{\infty} \beta^t U_t$, where the period utility function is given by:

$$U_t = \log C_t - \frac{\psi N_t^{1+\varphi}}{1+\varphi}, \tag{2}$$

with C_t and N_t denoting non-durable consumption and labor. $\beta \in (0,1)$ is the discount factor, $\varphi > 0$ is the inverse of the Frisch elasticity of labor supply, and $\psi > 0$ is the weight of labor disutility. Utility maximization is subject to the following budget constraint:

$$C_t + \frac{R_{t-1} b_{t-1}}{\pi_t} = w_t N_t + b_t + d_t - t_t,$$

where $\pi_t \equiv \frac{P_t}{P_{t-1}}$ is the rate of inflation in the price of consumption goods P_t, b_t denotes one-period risk-free bonds at the nominal interest rate R_t, w_t is the real wage, d_t is real profits from firms, and t_t is a lump-sum tax. The household chooses C_t, N_t, and b_t, and the associated first-order conditions can be stated as:

$$\psi N_t^{\varphi} = \frac{w_t}{C_t}, \tag{3}$$

$$\frac{1}{C_t} = \beta \mathrm{E}_t \frac{R_t C_{t+1}^{-1}}{\pi_{t+1}}. \tag{4}$$

3.2. Final goods producers

There is a perfectly competitive sector of final goods producers, who purchase goods from different intermediate goods producers, bundle them together, and sell them to the household or the government. Final goods producers have the following production function:

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

where Y_t is aggregate production of the final good, and $Y_{i,t}$ denotes the amount produced by individual firm i in the intermediate goods sector. The cost-minimization problem of the representative final goods firm gives rise to the following demand for intermediate good i:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t} \right)^{-\varepsilon} Y_t, \tag{5}$$

where $P_{i,t}$ is the price of good i, and where ε thus represents the elasticity of substitution between different intermediate goods.

[11] Ferrara et al. (2021) employ the news shocks of Ramey (2011), whereas Ben Zeev and Pappa (2017) identify an alternative (but closely correlated) shock series using medium-run restrictions. Ramey (2016) shows that neither the news shocks of Ramey (2011) nor the ones of Ben Zeev and Pappa (2017) pass a weak instruments test in samples starting after the Korean War and after World War II, respectively. According to Perotti (2011), similar concerns apply to the war dates of Ramey and Shapiro (1998) when the Korean war is excluded from the sample. This series is used by Edelberg et al. (1999) and Caldara and Kamps (2008) to obtain an increase in prices after a government spending shock.

[12] The model of Bianchi et al. (2019) features endogenous variations in TFP due to variable technology adoption and R&D investments in “knowledge capital”. Given our focus on the business-cycle effects of changes in fiscal policy, we abstract from the latter, as Bianchi et al. (2019) find that it plays virtually no role at business-cycle frequencies.

3.3. Intermediate goods producers

There is monopolistic competition in the intermediate goods sector. Individual firm i produces according to the following linear production function:

$$Y_{i,t} = V_{i,t} N_{i,t}. \tag{6}$$

$N_{i,t}$ is the amount of labor hired by firm i, and $V_{i,t}$ is the level of *utilized* technology. In turn, this is given by:

$$V_{i,t} = u_{i,t} A, \tag{7}$$

where $u_{i,t}$ denotes the firm-specific utilization rate, and A is the economy-wide and exogenous level of technology, which we set constant for simplicity. We let each firm decide on the rate at which it wishes to utilize the available technology in society. As in Bianchi et al. (2019), technology utilization may be interpreted as a measure of the capacity of the firm to adopt new knowledge or inventions into the production setup. As new inventions arrive, each firm needs to exert an effort to internalize this new technology. By endogenizing the rate of technology adoption, we allow firms to choose when to make this effort, subject to an adjustment cost whenever $u_{i,t}$ differs from its steady-state level u. We thus assume that it is costly for a firm to fully adopt new inventions into their production process as they arrive, for example because employees must be trained in using the new technology. We let the function $z\left(u_{i,t}\right)$ denote the adjustment costs associated with the choice of $u_{i,t}$. As in Bianchi et al. (2019), this function satisfies $z(u) = 0$, i.e., adjustment costs are zero in steady state. We also require $z'(u) > 0$ and $z''(\cdot) > 0$. Further, in line with the literature on variable utilization of capital (e.g., Christiano et al., 2005), we assume that $u = 1$. As we shall see, this choice pins down $z'(1)$. The curvature parameter $z''(\cdot)$ measures how quickly adjustment costs rise with changes in the rate of technology utilization.[13]

Each firm chooses labor inputs $N_{i,t}$ and technology utilization $u_{i,t}$ so as to minimize its costs subject to (6). This gives rise to the following first-order conditions:

$$w_t = mc_{i,t} \frac{Y_{i,t}}{N_{i,t}}, \tag{8}$$

$$z'\left(u_{i,t}\right) = mc_{i,t} \frac{Y_{i,t}}{u_{i,t}}, \tag{9}$$

where $mc_{i,t}$ is the multiplier associated with (6), and represents the real marginal cost of production. (8) equates the real wage to the marginal product of labor, while (9) states that the marginal cost of higher utilization, given by the increase in adjustment costs $z'\left(u_{i,t}\right)$, must equal the marginal product of a higher utilization rate. The utilization rate of technology affects the marginal cost in two ways: On the one hand, a higher rate of utilization allows the firm to increase production for given inputs of labor, effectively working like an increase in productivity. On the other hand, higher utilization is costly. If the former effect is sufficiently strong, a higher utilization rate reduces the marginal cost. In response to a government spending shock, this effect may even be strong enough to overcome the increase in the wage rate, thus paving the way for an equilibrium decline in the marginal cost and, as a consequence, in inflation.

When setting their price, intermediate goods firms are subject to a nominal rigidity in the form of quadratic price adjustment costs, as in Rotemberg (1982). Adjustment costs $\Upsilon_{i,t}$ are scaled by output and take the following form:

$$\Upsilon_{i,t} = \frac{\gamma}{2} \left(\frac{P_{i,t}}{P_{i,t-1}} - 1 \right)^2 Y_t,$$

where $\gamma > 0$ measures how costly it is to change prices. Firm i sets its price so as to maximize profits, and this problem can be written in real terms as:

$$\max_{P_{i,t}} \mathrm{E}_0 \sum_{t=0}^{\infty} q_{t,t+1} \left[\left(\frac{P_{i,t}}{P_t} - mc_{i,t} \right) Y_{i,t} - z\left(u_{i,t}\right) - \Upsilon_{i,t} \right],$$

subject to the demand function (5). Here, $q_{t,t+1} \equiv \beta \frac{\mathrm{E}_t \lambda_{t+1}}{\lambda_t}$ is the stochastic discount factor of the household, with λ_t denoting the marginal utility of consumption. Upon deriving the first-order condition, we impose a symmetric equilibrium in which all firms charge the same price, allowing us to state the optimality condition as:

$$1 - \varepsilon + \varepsilon mc_t = \gamma \left(\pi_t - 1\right) \pi_t - \gamma \mathrm{E}_t \frac{q_{t,t+2}}{q_{t,t+1}} \left(\pi_{t+1} - 1\right) \frac{Y_{t+1}}{Y_t} \pi_{t+1}. \tag{10}$$

This condition can be written on log-linearized form as a New Keynesian Phillips Curve.

[13] The only characteristic of the function z affecting the steady state is $z'(1)$. Moreover, as in Christiano et al. (2005) , only the ratio $\frac{z''(\cdot)}{z'(1)}$ affects the dynamics of our model outside steady state.

3.4. Monetary and fiscal policy

Fiscal policy is assumed to follow a balanced-budget rule:

$$g_t = t_t, \tag{11}$$

where government spending, g_t, satisfies:

$$\log g_t = \left(1 - \rho_G\right) g + \rho_G \log g_{t-1} + \varepsilon_t^G, \tag{12}$$

with the innovation ε_t^G following an i.i.d. normal process, and where g denotes government spending in steady state, while $0 \leq \rho_G < 1$ is the persistence of the shock.

The monetary policy rule is specified as follows:

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi}, \tag{13}$$

where $\phi_\pi > 1$ denotes the policy response to inflation deviations from its steady-state value π. For now we assume that the central bank responds only to inflation, while we allow for a reaction also to the output gap in Section 5.

3.5. Market clearing

Bonds are in zero net supply:

$$b_t = 0. \tag{14}$$

The labor market clears when:

$$\int_0^1 N_{i,t} di = N_t. \tag{15}$$

Finally, goods market clearing requires:

$$Y_t - z\left(u_{i,t}\right) - Y_{i,t} = C_t + g_t. \tag{16}$$

When solving the model, we consider only symmetric equilibria in which all firms make the same decisions, allowing us to discard subscript i's. We then log-linearize the equilibrium conditions around the non-stochastic steady state of the model, which is described in Appendix D.1. The log-linearized equilibrium conditions are presented in Appendix D.2.

4. Analytics of the model

To build intuition on the ability of the model to reproduce our empirical findings, we find it useful to offer some analytical insights. Under the assumption of a unitary (inverse) Frisch elasticity of labor supply ($\varphi = 1$), the log-linearized version of the model can be reduced to two equations in consumption and inflation (plus an exogenous process for government spending), as we show in Appendix D.3. Letting $\hat{x}_t$ denote the (log) deviation of a generic variable x_t from its steady-state value x, these two equations can be stated as:

$$-\hat{C}_t = \mathrm{E}_t\left(-\hat{C}_{t+1} + \phi_\pi \hat{\pi}_t - \hat{\pi}_{t+1}\right), \tag{EE}$$

$$\hat{\pi}_t = \beta \mathrm{E}_t \hat{\pi}_{t+1} + a\hat{C}_t - b\hat{g}_t, \tag{NKPC}$$

where a and b are functions of the deep parameters of the model (see Appendix D.3 for details). We provide necessary and sufficient conditions below for a and b to be strictly positive. (EE) simply combines the household's Euler equation with the monetary policy rule, while (NKPC) emerges by substitution of the remaining equilibrium conditions into the New Keynesian Phillips Curve. In Fig. 3, we provide a graphical representation of the model (EE)–(NKPC) in $(\hat{C}_t, \hat{\pi}_t)$-space. (EE) can be represented by a downward-sloping line (this can be seen most clearly in the case of non-persistent shocks, in which case $\mathrm{E}_t\hat{C}_{t+1} = \mathrm{E}_t\hat{\pi}_{t+1} = 0$), whereas (NKPC) implies an upward-sloping relationship between the two variables. Starting from the steady state of the model, indicated by the intersection of the curves *EE* and *NKPC* in Fig. 3, a positive shock to government spending ($\hat{g}_t > 0$) shifts the *NKPC*-curve *down*, leaving the *EE* curve unaffected. As shown by the curve labeled *NKPC'* in Fig. 3, an increase in government spending thus leads to a drop in inflation and an increase in consumption, in line with the empirical evidence of Section 2.

We proceed by deriving a closed-form solution of the model, as well as an analytical characterization of the conditions for a unique and determinate solution. We do this under the simplifying assumption that shocks to government spending have no persistence ($\rho_G = 0$). As we show in Appendices D.3 and D.4, the following statements are warranted:

Proposition 1. *The model has a determinate solution (and the parameter a is strictly positive) if and only if the curvature of the cost function associated with changes in the utilization rate of technology is above the following threshold:*

$$z''(\cdot) > z'(1)\frac{mc - \frac{g}{Y}}{2 - \frac{g}{Y}}. \tag{17}$$

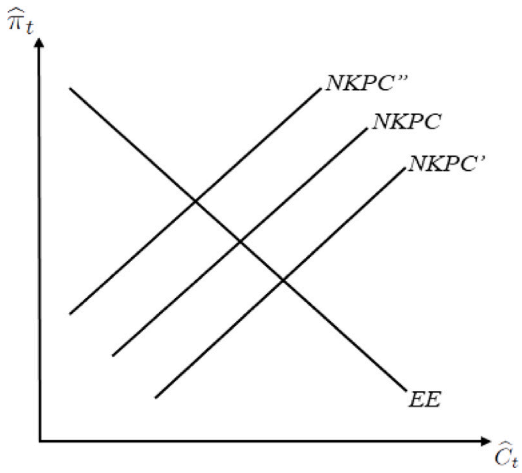

Fig. 3. The effects of a positive government spending shock. The NKPC'-curve refers to our baseline model, while the NKPC"-curve refers to the basic New Keynesian model without variable technology utilization.

Proposition 2. *If the model has a unique and determinate solution, it features a decline in inflation along with an increase in consumption on impact in response to a positive shock to government spending (and a strictly positive value of the parameter b) if and only if the curvature of the cost function is below the following threshold:*

$$z''(\cdot) < z'(1). \tag{18}$$

Proof. See Appendices D.3 and D.4. ■

Note that the steady-state value of mc is given by $mc = \frac{\varepsilon-1}{\varepsilon} < 1$. This means that there always exists a range of values for $z''(\cdot)$ for which both (17) and (18) are satisfied. For all values within this range, the model has a determinate equilibrium featuring a drop in inflation and an increase in consumption on impact.

We can explain these requirements as follows: (18) requires that the curvature $z''(\cdot)$ cannot be *too large*. If $z''(\cdot)$ is very high, changes to the utilization rate are very costly, so firms will be hesitant to make such changes. In the limiting case of $z''(\cdot) \to \infty$, firms will choose to never adjust the utilization rate, which will therefore remain constant, exactly as in a model without an endogenous utilization rate. Indeed, we show in Appendix D.5 that for $z''(\cdot) \to \infty$, the analytical solution to our model collapses to that of a baseline New Keynesian model, and that the latter always implies an increase in inflation—driven by the upward movement in the wage rate—along with a decline in consumption when $\widehat{g}_t$ increases. Graphically, this implies that the *NKPC*-curve is shifted *up*, as illustrated by the curve labeled *NKPC"* in Fig. 3.[14] To overturn this, and ensure a positive value of b and a downward shift in the *NKPC*-curve in Fig. 3, it is crucial that the utilization rate is sufficiently responsive, which in turn requires a limited cost of adjusting it.

Conversely, (17) provides a lower bound on the adjustment cost, effectively entailing that the rate of technology utilization cannot be too responsive. If this condition is not met, the model does not have a determinate solution. Intuitively, if the costs associated with changing the utilization rate are sufficiently small, the optimal utilization rate may tend to infinity in response to an expansionary shock. Thus, the adjustment cost function needs to display a certain degree of curvature for the costs to increase sufficiently with the utilization rate and contain the movements in the latter.

The analysis above establishes some general conditions under which our model is able to generate impact multipliers in line with the empirical evidence from Section 2. Effectively, our mechanism works much like an increase in the level of technology—in fact, it produces an increase in *measured* TFP (V_t), as we shall see below. The decline in marginal costs induces firms to reduce their prices, thus generating a decline in inflation. The central bank responds by reducing the nominal and real interest rate, thus facilitating an increase in consumption. In fact, in our simple environment, this is necessary and sufficient to generate an increase in private consumption. Again, this can be seen most easily in the case of non-persistent shocks, in which case (EE) simply states that consumption equals minus the nominal (and real) interest rate (in deviations from steady state). More generally, these insights carry over to the next section, where we lift some of the simplifying assumptions made in this section.[15,16]

[14] The basic New Keynesian model—subject to the same parameter restrictions as our model—features an Euler equation identical to (EE), and a rewritten New Keynesian Phillips Curve of the same form as (NKPC), but where the coefficient in front of $\widehat{g}_t$ is strictly negative. See Appendix D.5 for details.

[15] In Appendix E, we report simulated impulse-response functions from a calibrated version of the simple model of Section 3. We show that the model can reproduce our key empirical results when each of the assumptions of log utility, constant returns to scale in production, and no monetary policy reaction to the output gap are relaxed. We also offer a discussion of how each of these assumptions alters the analysis above.

[16] A final insight can be obtained from the simple model above: If we were to introduce a monetary policy shock into the model, the shock would appear in (EE), but not in (NKPC). A contractionary monetary policy shock would shift the *EE*-curve down along the *NKPC*-curve, generating a decline in inflation. In

5. An estimated model with capital formation

We now seek to evaluate the quantitative performance of our proposed mechanism within an estimated model of the U.S. economy. To this end, we augment the model along several dimensions in order to make it appropriate for estimation. Specifically, we introduce capital accumulation along with variable utilization of the physical capital stock, sticky wages, and habit formation in consumption. This brings our model closely in line with existing medium-scale general equilibrium models of the business cycle (e.g., Christiano et al., 2005). We first describe the details of these model extensions, and then turn to the estimation of the model.

5.1. Extended model

We introduce sticky wages into the model following the approach of Erceg et al. (2000). This implies that the household sector now consists of a continuum of monopolistically competitive households, each of which supplies a differentiated labor service. The demand for labor variety j is given by:

$$N_{j,t} = \left(\frac{W_{j,t}}{W_t}\right)^{-\varepsilon_W} N_t, \tag{19}$$

where $W_{j,t}$ denotes the nominal wage rate set by the household supplying labor type j, and $\varepsilon_W > 1$ denotes the elasticity of substitution between different types of labor. We assume that households face quadratic adjustment costs, which are given by:

$$\Upsilon_{j,t}^{W} = \frac{\gamma_W}{2}\left(\frac{W_{j,t}}{W_{j,t-1}} - 1\right)^2 Y_t, \tag{20}$$

where $\gamma_W > 0$ is a measure of the cost of changing the wage rate, and Y_t is the real adjustment cost base.

In the presence of internal habit formation in consumption, household j maximizes:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t - \theta C_{t-1}\right)^{1-\sigma}}{1-\sigma} - \frac{\psi N_{j,t}^{1+\varphi}}{1+\varphi}\right], \quad \sigma \neq 1,$$

where $0 \leq \theta < 1$ is the degree of habit formation, and $\sigma > 0$ is the coefficient of risk aversion. Following Christiano et al. (2005), our notation assumes that agents are heterogeneous with respect to the wage rate and hours worked, but homogeneous with respect to consumption and asset holdings. We assume that the capital stock is owned by households and rented to intermediate goods producers in each period. This means that households make the choices related to capital accumulation and utilization, while firms choose the amount of utilized capital to employ in production. The law of motion for capital is given by:

$$K_t = (1-\delta) K_{t-1} + \left[1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t, \tag{21}$$

where K_t and I_t denote the stock of capital and the investment in new capital, $0 \leq \delta < 1$ is the rate at which capital depreciates, while $\kappa > 0$ denotes quadratic investment adjustment costs. The budget constraint of household j thus becomes (in real terms):

$$C_t + I_t + \frac{R_{t-1} b_{t-1}}{\pi_t} = w_{j,t} N_{j,t} + \left(r_t^K u_t^K - z^K\left(u_t^K\right)\right) K_{t-1} + b_t + d_t - t_t - \Upsilon_{j,t}^{W}. \tag{22}$$

Note that the left-hand side now incorporates investment expenses, while the right-hand side includes wage adjustment costs as well as rental income from utilized capital, with r_t^K and u_t^K denoting the rental rate and the capital utilization rate, respectively. $z^K\left(u_t^K\right)$ denotes capital utilization costs. The household chooses consumption, bond holdings, investment, capital, and the real wage, with the latter decision giving rise to a New Keynesian Wage Phillips Curve. We present all first-order conditions of the extended model in Appendix F.

Intermediate goods producers choose capital, labor, and technology utilization. Their production function is now given by:

$$Y_{i,t} = u_{i,t} A N_{i,t}^{1-\alpha}\left(u_t^K K_{i,t-1}\right)^{\alpha}, \tag{23}$$

with $0 < \alpha < 1$. Cost minimization gives rise to a standard first-order condition for the demand for capital, which we present in Appendix F, while the first-order conditions for labor and technology utilization are still given by (8) and (9). The aggregate resource constraint then reads:

$$Y_t - z\left(u_{i,t}\right) - z^K\left(u_t^K\right) K_{t-1} - \Upsilon_{i,t} - \Upsilon_{j,t}^{W} = C_t + I_t + g_t. \tag{24}$$

The monetary policy rule now allows for an output gap reaction and interest rate smoothing:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r}\left[\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi}\left(\frac{Y_t}{Y}\right)^{\phi_y}\right]^{1-\rho_r}, \tag{25}$$

---

other words, our model is not able to account for the price puzzle of monetary policy (Sims, 1992). The reason is that a government spending shock affects natural (i.e., flexible-price) output via its effect on labor supply, and thus exerts a direct effect on inflation, whereas a monetary policy shock leaves natural output unaffected.

with $\phi_y \geq 0$ denoting the policy response to output fluctuations, and $0 \leq \rho_r < 1$ denoting the degree of smoothing in the monetary policy process.

Finally, we need to specify and parametrize the functional form of the adjustment costs associated with changes in the technology utilization rate. These are given by[17]:

$$z\left(u_t\right) = \chi_1\left(u_t - u\right) + \frac{\chi_2}{2}\left(u_t - u\right)^2, \tag{26}$$

where $\chi_1, \chi_2 > 0$, and where $u = 1$ denotes the steady-state level of u_t. This implies that $z'\left(u_t\right) = \chi_1 + \chi_2\left(u_t - u\right)$. The adjustment costs of the utilization rate of capital, $z^K\left(u_t^K\right)$, take the same functional form, with $\chi_1^K, \chi_2^K > 0$. This completes the description of our extended model. We present the steady state and the log-linearization in Appendix F.

5.2. Estimation strategy

Following Christiano et al. (2005), among others, we estimate (a subset of) the parameters of the model by matching the model-implied impulse responses to a government spending shock to the empirical responses presented in Section 2.1.[18] To this end, we first split the parameters into two groups. $\omega_1 = \left\{\alpha, \beta, \varepsilon, \varepsilon_W, \chi_1, \chi_1^K, \psi, \frac{g}{Y}\right\}$ contains the parameters that we choose to calibrate. We let $\alpha = 0.25$ as in Galí (2015) . We set $\beta = 0.99$, implying an annualized real interest rate of 4% in the steady state. Following most of the literature, we set $\varepsilon = 6$, implying a steady-state markup of 20 percent. We also set $\varepsilon_W = 6$. The weight on disutility of labor hours in the utility function, ψ, is calibrated so that $N = 1/4$ (this only affects the scale of the economy). The ratio of government spending to output matches the sample average in the US for the period 1960–2019, which equals $\frac{g}{Y} = 0.25$. Finally, χ_1 and χ_1^K are calibrated to ensure $u = u^K = 1$ in steady state, implying values of $\chi_1 = 0.45$ and $\chi_1^K = 0.02$. We then collect in $\omega_2 = \left\{\gamma, \gamma_W, \delta, \theta, \kappa, \rho_G, \rho_r, \sigma, \varphi, \phi_\pi, \phi_y, \chi_2, \chi_2^K\right\}$ the parameters to be estimated. Let $\Lambda\left(\omega_2\right)$ denote the model-implied impulse responses, which are functions of the parameters, while $\widehat{\Lambda}$ denotes the corresponding empirical estimates from our VAR model. We obtain the vector of parameter estimates $\widehat{\omega}_2$ as:

$$\widehat{\omega}_2 = \arg\min_{\omega_2}\left(\Lambda\left(\omega_2\right) - \widehat{\Lambda}\right)' W \left(\Lambda\left(\omega_2\right) - \widehat{\Lambda}\right). \tag{27}$$

The weighting matrix W is a diagonal matrix with the inverse of the sample variances of the VAR-based impulse responses along the diagonal. Effectively, this means that we are attaching higher weights to those impulse responses that are estimated most precisely. We match impulse responses for the eight variables reported in Fig. 1 plus investment, which we now include in our structural VAR model, using the responses during the first 20 quarters after the shock. We conduct the estimation on our baseline sample ending in 2008:Q3.[19] In addition to the intervals over which they are defined, we impose certain realistic bounds on some of the estimated parameters, as discussed in the next subsection.[20]

5.3. Estimation results

We report the estimated parameter values in the first column of Table 2, as well as the associated standard errors, which are computed using an application of the delta method, as described, e.g., in Hamilton (1994). We first note that all parameters take on values that are generally in line with the existing literature. The estimated degrees of nominal rigidities are consistent with prices and wages being reset every $2\frac{1}{2}$ quarters and every $6\frac{1}{2}$ quarters, respectively. While the former number is close to existing estimates (e.g., Christiano et al., 2005), the degree of wage stickiness is somewhat higher than found in most studies, although some authors obtain even higher estimates (e.g., Herbst and Schorfheide, 2014). The depreciation rate of capital ($\delta = 0.010$) and the degree of habit formation ($\theta = 0.098$) are both on the lower end of the range of existing estimates, though the latter is rather imprecisely estimated. The estimated investment adjustment cost parameter ($\kappa = 1.798$) is modest, with available estimates of this parameter displaying substantial variation. The estimate of φ implies a Frisch elasticity of labor supply close to 1.3, representing a middle ground between microeconometric studies and macroeconomic models. The estimated coefficient of risk aversion ($\sigma = 0.504$) is relatively low in order to generate a sizable increase in consumption in response to the observed drop in the interest rate. The parameters of the monetary policy rule imply a predominance of inflation over output gap stabilization, although the estimates of ϕ_π and ϕ_y are almost driven to their lower bounds of 1.01 and 0, while the degree of interest rate smoothing reaches its upper bound of 0.9. As we discuss in Appendix E.3, a low value of ϕ_y facilitates an increase in consumption alongside a decline in prices. Higher values of ϕ_π would lead to smaller absolute movements in inflation.

[17] This functional form satisfies the requirements stated by Bianchi et al. (2019) and is consistent with the standard specification of capital adjustment costs in the literature; e.g. in Christiano et al. (2005).

[18] We match the empirical impulse responses directly to those from our DSGE model. An alternative approach would be to simulate a long, artificial data set from the DSGE model, estimate a VAR model on this data, and use the so obtained impulse responses in the matching exercise. A necessary step is to add additional structural shocks to the linearized model to avoid stochastic singularity. We have performed this exercise and confirmed that the impulse responses obtained from it are very similar to the “true” model responses, thus lending support to the approach we have taken.

[19] We have also conducted an estimation on the longer sample ending in 2019:Q4. This did not lead to major changes neither in the estimated parameter values, nor in the implied impulse responses, mainly because the impulse responses obtained from the VAR model are very similar, as discussed in Section 2.3.

[20] Since the vector of estimated parameters includes both the parameters in the monetary policy rule (ϕ_π and ϕ_y) and the curvature of the technology utilization cost function (χ_2), our estimation procedure sometimes draws parameter vectors for which the model has no determinate solution. To circumvent this problem, we introduce a penalty function that drives the procedure away from such cases.

Table 2
Parameter estimates.

Parameter	Description	Estimates	
		Baseline model	No tech. util.
γ	Rotemberg price adj. costs	62.022 (3.319)	536.276 (134.677)
γ_W	Rotemberg wage adj. costs	601.166 (24.317)	2122.730 (466.419)
δ	Capital depreciation rate	0.010 (0.002)	0.040 (0.049)
θ	Consumption habits	0.098 (0.844)	0.900 (3.573)
κ	Investment adj. costs	1.798 (1.346)	0.327 (1.392)
ρ_G	Persistence of spending shock	0.941 (0.009)	0.966 (0.007)
σ	Relative risk aversion	0.504 (0.068)	4.000 (120.964)
φ	Inverse Frisch elasticity	0.764 (0.196)	3.000 (46.682)
ϕ_π	Taylor coeff. on inflation	1.014 (0.149)	1.010 (1.995)
ϕ_y	Taylor coeff. on output gap	0.014 (0.003)	0.000 (0.081)
ρ_r	Interest rate smoothing	0.900 (0.015)	0.900 (0.796)
χ_2^K	Capital utilization adj. costs	8.001 (3138.724)	0.001 (0.036)
χ_2	Technology utilization adj. costs	0.304 (0.058)	N/A

Notes: We report standard errors in brackets, obtained using the delta method.

Finally, we obtain a parameter estimate of $\chi_2 = 0.304$. The parameter appears to be well-identified in the data with a standard error of 0.058. As discussed below, the value of χ_2 is low enough to ensure a substantial yet realistic response of technology utilization to government spending shocks. In contrast, the estimate of the parameter governing the utilization rate of capital, χ_2^K, is much higher (8.001) and very imprecisely estimated. This indicates that, given the presence of variable technology utilization, the additional margin introduced through variable capital utilization is redundant for the model to match the data. To dig deeper into this question, we estimate a version of the model without variable technology utilization, reported in the second column of Table 2. In this case, the parameter χ_2^K is estimated at a value very close to zero, and with a modest standard error. In other words, there seems to be a role for variable capital utilization when we shut off the main mechanism of this paper. Nonetheless, as we shall see next, this alternative model fails to match the empirical evidence along several crucial dimensions.[21]

We report the estimated impulse-response functions from the model in Fig. 4 alongside their empirical counterparts from the VAR model. The estimated DSGE model with variable technology utilization ('Baseline') yields a close match of the responses of most variables in the data. Specifically, the model generates a decline in prices largely similar to that observed in the data. While the model's response is slightly more persistent, it always remains within the estimated confidence bands from the VAR model. The baseline model also generates a hump-shaped increase in consumption, although this falls short of the magnitude observed in the data. The responses of output, the real wage, TFP, investment, and government spending itself are close to their empirical counterparts, mostly remaining within the estimated confidence bands. In contrast, the alternative model without variable technology utilization delivers a much weaker fit of the empirical evidence. Notably, this model produces a steady increase in the price level accompanied by a flat response of consumption. We explain the inability of this model to generate a decline in prices carefully in the next subsection.

Our baseline model outperforms the alternative one along most dimensions, suggesting that the data favors the presence of variable technology utilization. The increase in consumption allows the baseline model to match the increase in output quite well, whereas the output response in the alternative model falls short of the VAR estimate. Furthermore, variable technology utilization is necessary in order to match the magnitude of the increase in TFP and the real wage. The increase in utilization raises measured productivity, thus driving up the marginal products of both labor and capital, allowing the baseline model to closely match the responses of the real wage and investment. In the absence of this mechanism, the increase in capital utilization is insufficient to deliver a similar-sized increase in the real wage.[22] Finally, both models struggle to generate a decline in the nominal interest rate and an increase in tax revenues of the magnitudes observed in the data.[23]

[21] In addition, most parameters of this model reach the bounds we have imposed, including the degree of habit formation, the inverse Frisch elasticity, the degree of risk aversion, and the parameters of the monetary policy rule. The same is true for the estimates of γ and γ_W, where we impose an upper bound corresponding to prices and wages being set every $6\frac{2}{3}$ quarters (corresponding to a Calvo parameter of 0.85). Note that the mapping from γ_W to the Calvo parameter is different in the two model versions, as it depends on the value of φ.

[22] Since we use the non-utilization-adjusted productivity measure of Fernald (2014) in the VAR evidence, the model-based measure of TFP in our extended model includes also the utilization rate of capital.

[23] Matching the response of tax revenues would require a more thorough treatment of public finances than warranted by our assumption of a balanced government budget each period. The muted response of the nominal interest rate reflects the tradeoff between matching the drop in prices and the increase in economic activity, which we discuss further in Appendix E.3. We have experimented with an interest rate rule augmented with a reaction to output growth and interest rate smoothing of order two, which was found by Coibion and Gorodnichenko (2011) to fit U.S. data during the Great Moderation well. However, this led to very small changes in the impulse responses of all variables, including the interest rate.

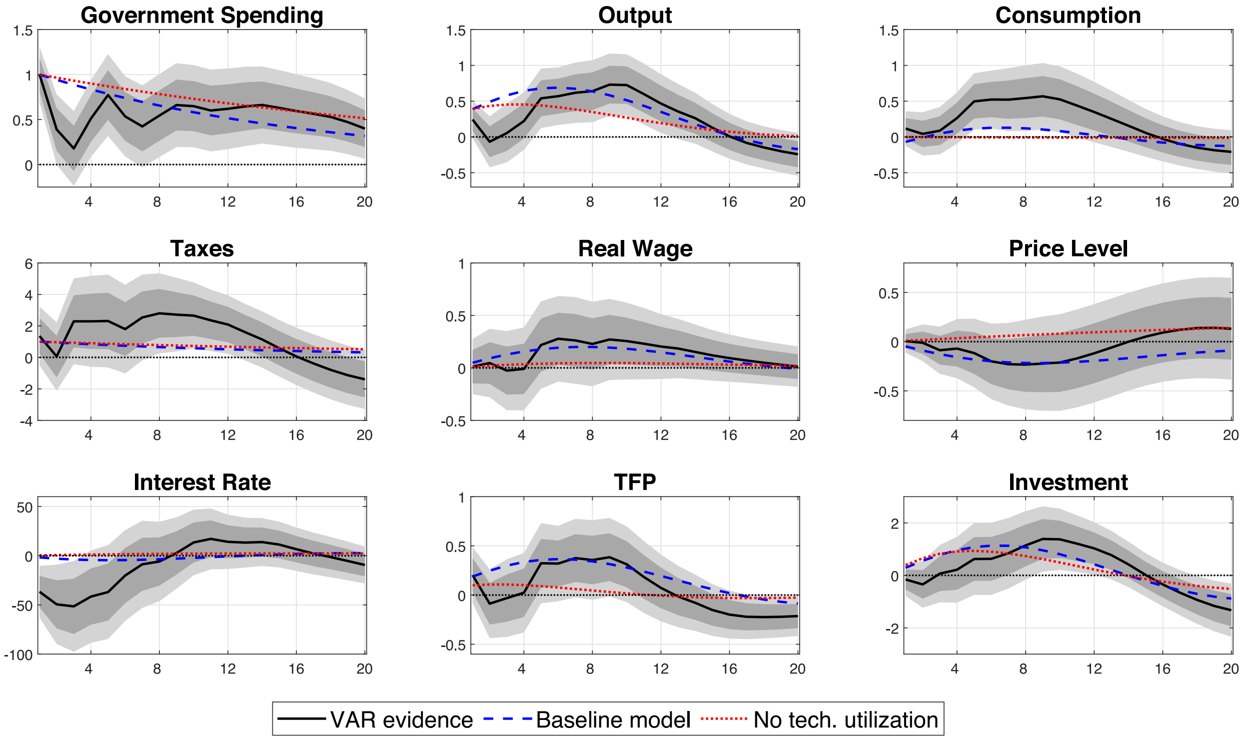

Fig. 4. Impulse responses to a government spending shock of 1 percent. Solid black lines: estimated VAR model using the identification based on forecast errors. Gray areas: 68 percent confidence bands (dark gray) and 90 percent confidence bands (light gray) from the VAR model. Dashed blue lines: estimated baseline DSGE model. Dashed red lines: estimated DSGE model without variable technology utilization. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

5.4. External validity and alternative explanations

This section provides additional empirical evidence in favor of variable technology utilization and explores whether alternative mechanisms proposed in the literature can help explain our empirical findings.

First we seek to verify that the movements in the rate of technology utilization required to match the data are not unreasonable. Since data on technology utilization is not readily available, there is no empirical counterpart against which to evaluate the implied response of this variable. However, Bianchi et al. (2019) argue that their model-implied rate of technology utilization is closely correlated with data on the software expenditures of firms; one potential measure of technology adoption. In Fig. 5 we report the response of software expenditures when this variable is included in our VAR model of Section 2, using both forecast-error and Cholesky identification. In both cases, we observe a significant increase in this variable after a government spending shock, thus providing indirect evidence in support of our proposed mechanism. Moreover, the increase in the rate of technology utilization in our estimated baseline model is small in both an absolute and a relative sense. As seen from the left panel of Fig. F.1 in Appendix F, this rate increases by around 0.4 percent at the peak, which is clearly smaller than the increase in software expenditure in the data. The increase in technology utilization amounts to roughly half of the increase in output in the model. In comparison, Christiano et al. (2005) find that the rate of capital utilization moves roughly 1-for-1 with output in the data and in their model.[24]

Our proposed mechanism is also consistent with existing empirical evidence that technology adoption is procyclical (e.g., Comin, 2009; or Anzoategui et al., 2019), and that shocks to expected demand at the firm level lead to increased innovation and higher TFP at that firm (Aghion et al., 2018, Ignaszak and Sedlacek, 2021). Moretti et al. (2019) find that government spending on defense-related R&D stimulates private R&D activity and, subsequently, TFP. More generally, differences in technology adoption rates across firms account for a large share of variations in TFP (Comin and Mestieri, 2014).

Next, we consider whether alternative mechanisms could potentially account for our empirical results. These mechanisms include variable capital utilization (as in the previous section), variable labor utilization, and learning-by-doing. The previous subsection showed that variable capital utilization was unable to generate a decline in prices. To explain this finding, it is useful to consider

[24] This is also the case in our alternative model without variable technology utilization. In that model, as seen from the right panel of Fig. F.1 in Appendix F, the rate of capital utilization increases by around 0.4 percent, which roughly matches the increase in output in that model (see Fig. 4).

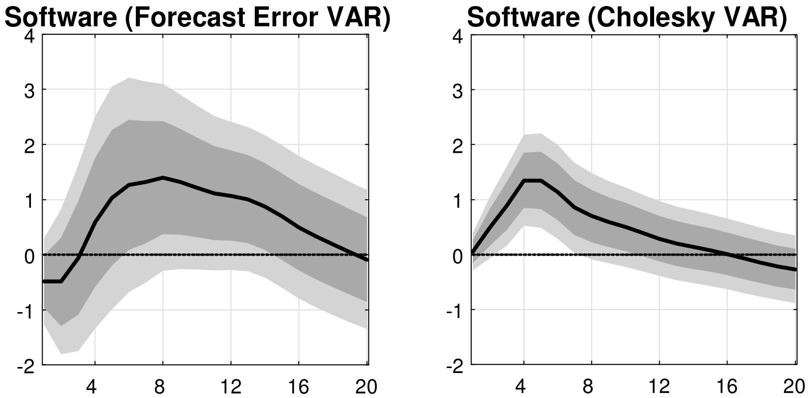

Fig. 5. The dynamic response of software expenditures to a shock to government spending. Estimates obtained using the identification based on forecast errors (left panel) and Cholesky decomposition (right panel). The black line denotes the estimated response, while the gray areas represent the 68 percent confidence bands (dark gray) and the 90 percent confidence bands (light gray).

the expression for the marginal cost in the model outlined in Section 5.1. As shown in Appendix F, this expression is given by:

$$mc_t = \frac{w_t^{1-\alpha}\left(r_t^K\right)^\alpha}{(1-\alpha)^{1-\alpha}\alpha^\alpha A u_t}. \tag{28}$$

Notably, while the rate of technology utilization u_t exerts a negative impact on mc_t, the rate of capital utilization does not appear in this expression. This reflects the difference between variable utilization of technology and capital, respectively. Since firms pay rental rates on *utilized* capital—as seen from (22)—any increase in the utilization rate entails an increase in firms' rental cost of capital, in addition to the adjustment cost $z^{K\prime}\left(u_t^K\right)$ of higher utilization. Likewise, it can be shown that variable *labor* utilization does not affect firms' marginal costs, as firms would pay wages to the *utilized* workforce they employ in order to compensate workers for, e.g., extra shifts or effort. In contrast, the only cost of utilizing the technology level at a higher rate comes from the adjustment cost, since technology itself is free to use; thus facilitating a decline in marginal costs in equilibrium. This explains why the estimated model with only capital utilization in the previous subsection, as well as a model with variable labor utilization, fails to generate a decline in prices.[25,26]

Another alternative is the learning-by-doing (LBD) mechanism studied by D'Alessandro et al. (2019). Following Chang et al. (2002), these authors assume that productivity is a labor-augmenting stock variable (termed the "knowledge stock") which depends positively on past hours worked. In this case, it is possible to show that the stock of accumulated knowledge capital shows up—raised to the power of $(1-\alpha)$—in the denominator of (28), implying that the LBD mechanism should in theory have a chance of generating a decline in prices after a government spending shock.

To explore its quantitative implications, we introduce the LBD mechanism into our model in lieu of variable technology utilization. The key parameters of the mechanism are the persistence of the stock of knowledge capital and its elasticity with respect to past hours worked (denoted ρ_X and μ_N, respectively). Following D'Alessandro et al. (2019), we rely on the microeconometric estimates of these parameters of Chang et al. (2002).[27] We then estimate the remaining parameters of this model version. The estimation results are reported in Appendix C. As seen from Fig. C.6, while the estimated responses from this model ('LBD restricted') have the correct sign, they fail to match the magnitude, and in many cases the hump-shape, of the responses in the data. Particularly, the responses of both prices and consumption are almost flat. We have also performed an estimation in which we estimate the LBD parameters, μ_N and ρ_X, freely (see Fig. C.6). While this substantially improves the empirical fit of the LBD model, the estimated elasticity (μ_N) is strongly at odds with empirical evidence, as it is an order of magnitude larger than the microeconometric estimate provided by Chang et al. (2002) (see Table C.1 in Appendix C).

Thus, while LBD may well be complementary to variable technology utilization, our findings point to important drawbacks associated with this mechanism. First, it relies on a slow-moving stock variable to obtain effects at business-cycle frequencies. In contrast, Bianchi et al. (2019) find that the accumulation of knowledge capital plays virtually no role for fluctuations in TFP at business-cycle frequencies. Second, because LBD only affects the labor input, it has a weaker impact on the marginal cost as

[25] We have confirmed that this is true for an estimated model with variable labor utilization, which produced almost identical impulse responses as the model with variable capital utilization (not reported).

[26] We have also performed an estimation in which we include data on capital utilization obtained from Fernald (2014) in the matching exercise. This led only to small changes in our results, confirming that the model with capital utilization fails to produce a decline in prices not because capital utilization increases by too little, but because the mechanism itself does not exert a negative impact on marginal costs.

[27] Based on the Panel Study of Income Dynamics Chang et al. (2002) report estimates of $\mu_N = 0.111$ and $\rho_X = 0.797$, both of which are very precisely estimated.

Table 3
Government spending multipliers.

	"Normal" times	Zero lower bound
Baseline model	1.40	0.66
Alternative model (no tech. util.)	1.09	1.60

compared to variable technology utilization, all else equal. We therefore conclude that LBD struggles to account for the empirical results unless the LBD channel is implausibly strong, reflecting the drawbacks of this mechanism.[28]

6. Model dynamics at the zero lower bound

Over the last decade, considerable attention has been devoted to understanding the effects of government spending shocks when the nominal interest rate is at its zero lower bound (ZLB). As discussed by Bilbiie (2021), the theoretical literature is dominated by two different strands. The first holds that government spending shocks are inflationary at the ZLB, thus leading to a drop in the real interest rate, an increase in private consumption, and a large government spending multiplier. Advocates of such "Keynesian" effects include Christiano et al. (2011) and Eggertsson (2011), and typically build on theories in which the ZLB episode is generated by a fundamental shock to the economy. The second—sometimes dubbed "neo-Fisherian"—view starts from the ZLB episode arising from a non-fundamental "confidence" shock, and tends to arrive at the exact opposite predictions; see, e.g., Benhabib et al. (2001) and Mertens and Ravn (2014). As we now show, the presence of variable technology utilization leads to important modifications of the results obtained in this literature.

We first return to the simplified model studied in Sections 3 and 4 to obtain analytical insights. In Appendix G, we show that under the assumption that the nominal interest rate is pegged permanently at zero, we obtain either "Keynesian" or "neo-Fisherian" effects depending on the persistence of the government spending shock. Notably, in our model with variable technology utilization, the conditions under which either effect obtains are flipped upside down vis-a-vis the standard New Keynesian (NK) model. In our baseline model—provided, crucially, that the curvature of the cost function associated with changes in the rate of technology utilization falls in the exact same range of values studied in Section 4—the responses of consumption and inflation are *negative* (leading to "neo-Fisherian" effects) under low or moderate shock persistence, but turn *positive* (giving rise to "Keynesian" effects) if the shock is very persistent. Notably, the predictions of the textbook NK model are the exact opposite. As shown by Bilbiie (2021), "neo-Fisherian" effects of government spending shocks are more likely to obtain in the textbook NK model when shocks are very persistent.[29,30] Intuitively, the presence of variable technology utilization overturns the responses of inflation and consumption at the ZLB for the same reasons it did so away from it, which we explained in Section 4. In Fig. G.1 in Appendix G, we document how the responses of inflation and consumption vary over a range of values of the technology utilization cost parameter χ_2 and the persistence of the government spending shock, ρ_G.[31]

We turn next to the estimated model of the previous section. Following Christiano et al. (2011), we introduce a shock to households' discount factor and use this shock to bring the economy to the ZLB. Thus, the origin of the ZLB episode is a fundamental shock to the economy. We assume that the economy stays at the ZLB for eight quarters. We then simulate a shock to government spending within our baseline model estimated in Section 5, as well as in the estimated alternative model without variable technology utilization. For the numerical implementation, we use the *Occbin* toolkit of Guerrieri and Iacoviello (2015).

In Table 3, we present the government spending multipliers from each of the two models at the ZLB, alongside the corresponding multipliers in "normal" times, i.e., away from the ZLB.[32] Following the suggestion of Ramey (2019), we focus on present-value cumulative multipliers, though our conclusions are confirmed if we focus on the multipliers on impact or at the peak.[33] The results in the table pose an interesting paradox for fiscal policy: While variable technology utilization makes government spending *more* effective in stimulating aggregate demand in normal times, it makes it *less* effective when the economy is constrained by the ZLB. Indeed, our baseline model features a *lower* multiplier at the ZLB (0.66) than in normal times (1.40), whereas the multiplier in the

[28] Another reason why learning-by-doing may be less important at business-cycle frequencies is that labor market churn—the simultaneous occurrence of hiring and job separations at the same business establishment—is strongly procyclical (Burgess et al., 2000; Lazear and Spletzer, 2012), implying that workers and firms remain together for shorter periods of time during expansions, which may hinder learning-by-doing at the firm level.

[29] As Bilbiie (2021) points out, very persistent shocks lead to an overcompensating negative income effect on desired savings arising from the increased tax burden. To ensure zero savings in equilibrium, the real interest rate must rise. In our model with variable technology utilization, this negative income effect is dominated by a positive income effect arising from higher marginal products of labor and capital—as reflected by the increase in consumption observed in the previous sections—thus reversing the argument.

[30] Uribe (2021) finds evidence of substantial "neo-Fisherian" effects in the US in response to permanent interest rate shocks, but does not study fiscal shocks.

[31] We also show that for the range of values considered in Section 4, increased price flexibility makes it *less* likely to observe "neo-Fisherian" effects, which again contrasts with the predictions of the baseline New Keynesian model (Bilbiie, 2021).

[32] To ensure comparability across models, we have changed the persistence of the government spending shock in the alternative model from the estimated value of 0.966 to the value estimated in the baseline model, 0.941. This does not alter the conclusions drawn in this section.

[33] Following Mountford and Uhlig (2009), the present-value cumulative multiplier M_j is computed as $M_j = \frac{\sum_{i=1}^{j}(1+r)^{-i}\hat{y}_i}{\sum_{i=1}^{j}(1+r)^{-i}\hat{g}_i}\frac{1}{g/Y}$, where 1 is the period in which the shock hits, and where we set $j = 20$ to focus on the response up to five years after the shock. Further, r is the average nominal interest rate over the period 1960–2019, which equals 4.54 percent, while $\hat{g}_i$ denotes the response of government spending at horizon i, and $\hat{y}_i$ the corresponding response of total value added (defined as the sum of private and public consumption plus investment). Finally, $g/Y = 0.25$ as in the previous section.

alternative model is *higher* at the ZLB (1.60) than away from it (1.09), as in other analyses of standard NK models and fundamental ZLB episodes. The intuition behind this result can be explained as follows. In the standard NK model without variable technology utilization, a fiscal expansion is inflationary. The spending multiplier is larger at the zero lower bound because the monetary authority does not raise the nominal interest rate in response to the rise in inflation. This leads to a drop in the real interest rate, stimulating private economic activity, as can be seen from Fig. G.3 in Appendix G. In contrast, in our model with variable technology utilization, the shock to government spending is disinflationary. In the face of a fixed nominal interest rate, the shock therefore leads to an *increase* in the real interest rate, dampening private economic activity. As a result, the fiscal multiplier is *lower* at the zero lower bound than in normal times.

Our findings yield novel insights on the role of fiscal policy at the ZLB. We find that government spending shocks at the ZLB may give rise to "neo-Fisherian" effects, even if the liquidity trap is triggered by a fundamental shock, provided that government spending affects the supply-side of the economy. The finding of a low spending multiplier at the ZLB is similar to that of Mertens and Ravn (2014), although these authors obtain this result in the context of a non-fundamental shock to the standard NK model. Our results therefore relate to the set of testable implications derived by Bilbiie (2021) to determine whether a ZLB episode is of the fundamental or confidence-driven type. While he argues that negative responses of inflation and consumption to a government spending shock are indications of the latter, our findings point to the possibility of observing such effects even in a fundamental ZLB episode.

The empirical literature is yet to reach a consensus on whether fiscal multipliers are higher-than-normal at the ZLB or not. The evidence for the US reported by Ramey and Zubairy (2018) is somewhat mixed, although they do obtain high multipliers (around 1.5) at the ZLB in some specifications. Caggiano et al. (2015) report evidence of high multipliers in the US during very deep recessions (e.g., because of a constrained reaction of nominal interest rates due to the ZLB). In contrast, Dupor and Li (2015) find no evidence of any substantial increase in expected inflation in the US in response to a fiscal expansion under passive monetary policy, which would be required to obtain a high multiplier. Using data from Japan, Miyamoto et al. (2018) find that the multiplier is substantially higher at the ZLB than away from it. Wieland (2019), on the other hand, finds that negative supply shocks are not expansionary at the ZLB in Japan. He shows that this is equivalent to rejecting the presence of high fiscal multipliers at the ZLB. In sum, the literature has not yet produced firm results regarding the size of fiscal multipliers at the ZLB. Our results echo the call of Bilbiie (2021) for more empirical research on this topic.

7. Conclusion

The assumption that increases in government spending are inflationary is a key building block of many theoretical accounts of fiscal policy. However, this paper presents empirical evidence that prices do not increase in response to a fiscal expansion. Instead, the price response is muted or even negative. The puzzling response of prices coincides with increases in output, consumption, and TFP. To account for these findings, we propose a model of variable technology utilization in the spirit of Bianchi et al. (2019), thus contributing to an emerging literature on endogenous productivity in business-cycle models. We show that the model can replicate the observed response of prices and other key macroeconomic variables to a government spending shock. The model implies that the government spending multiplier is substantially lower when the economy is facing a binding zero lower bound on the nominal interest rate, as compared to normal times. Our findings highlight the importance of accounting for potential supply-side effects in order to gain a more complete understanding of the transmission of fiscal policy. We think of this as a fruitful avenue for future research.

Appendix A. Literature survey: fiscal policy studies

See Table A.1.

Appendix B. The data

All data used in the baseline specification of our SVAR model—with the exception of total factor productivity (TFP) and the forecast errors of Auerbach and Gorodnichenko (2012)—are taken from Federal Reserve Economic Data (FRED). The series are described in detail below with series names in FRED indicated in brackets:

G_t: Government consumption expenditure and gross investment (GCECE1, seasonally adjusted, Chained 2012 $).

Y_t: Real GDP (GDPC1, seasonally adjusted, Chained 2012 $).

C_t: Real Personal Consumption Expenditures (PCECC96, seasonally adjusted, Chained 2012 $).

T_t: Government current tax receipts (W054RC1Q027SBEA, seasonally adjusted) – Government current transfer receipts (A084RC1Q027SBEA, seasonally adjusted) – Government interest payments (A180RC1Q027SBEA, seasonally adjusted) – Government subsidies (GDISUBS, seasonally adjusted).[34] We convert from nominal to real terms using the GDP deflator (see below).[35]

P_t: Personal Consumption Expenditures Price Index (PCECTPI, seasonally adjusted, 2012=100).

[34] We have also computed an alternative tax measure that includes also "Government income receipts on assets" (FRED code: W058RC1Q027SBEA) and "Government current transfer receipts" (FRED code: W060RC1Q027SBEA) on the revenue side. Using this series in our VAR model has virtually no impact on our results.

[35] Since the series turns negative at some points in time, we add a constant to it before taking logs.

Table A.1
Empirical estimates of inflation.

Fiscal policy study	Response of prices/inflation	Method	Identification	Countries	Variables	Sample period
Edelberg et al. (1999)	Prices increase	SVAR	Ramey–Shapiro war dummies	US	Real GDP, interest rate, oil prices, real defense purchases, prices. All in logs, except interest rate.	1948:Q1–1996:Q1
Fatas and Mihov (2001a)	Prices are insignificant	SVAR	Semi-structural VAR	US	Log of private output, log of prices, ratio of primary deficit to output and interest rate.	1960:Q1-1996:Q4
Fatas and Mihov (2001b)	Prices decline	SVAR	Cholesky	US	Government spending, private output, prices, taxes, interest rate. All in logs, except interest rate.	1960:Q1-1996:Q4
Blanchard and Perotti (2002)	Not reported	SVAR	Cholesky	US	Taxes, government spending, GDP. All in logs and real per capita terms.	1960:Q1–1997:Q4
Canzoneri et al. (2002)	Inflation declines	SVAR	Cholesky	US	Real per capita taxes, government spending, and GDP, inflation, commodity prices, interest rate, per capita bank reserves, and ten-year constant maturity Treasury yield. All in logs except inflation and interest rates.	1951:Q1–1995:Q4
Burnside et al. (2004)	Not reported	SVAR	Ramey–Shapiro war dummies	US	GDP, government spending, capital and labor income tax rates, and one rotating variable. All in logs and real per capita terms, except tax rates.	1947:Q1-1995:Q4
Perotti (2005)	Mixed response of inflation (negative for US)	SVAR	Institutional information on gov. spending elasticities	5 OECD countries	Logs of real per capita government spending, taxes, and output, inflation, and interest rate.	1960:Q1–2001:Q4 (subj. to data availability)
Canova and Pappa (2007)	Mixed response of prices	Bayesian panel SVAR	Sign restrictions	47 US states + 9 EMU countries	Endogenous variables: Local to union-wide prices, real per capita GDP, employment, local taxes, local government spending (both real per capita). All in logs.	US: 1969–1995, EMU: 1997:Q1–2003:Q3
Galí et al. (2007)	Not reported	SVAR	Cholesky	US	Government spending, GDP, hours, consumption, private nonresidential investment, real wage, budget deficit, and personal disposable income. All quantity variables in logs (or ratios to trend GDP) and in per capita terms.	1954:Q1-2003:Q4
Caldara and Kamps (2008)	Inflation increases	Bayesian SVAR	Cholesky, sign restrictions, Ramey–Shapiro war dummies	US	Government spending, GDP, inflation, taxes, and interest rate. Quantity variables in logs and real per capita terms.	1955:Q1–2006:Q4
Mountford and Uhlig (2009)	Prices decline	SVAR	Sign restrictions	US	GDP, consumption, government spending, taxes, real wage, private non-residential investment, interest rate, adjusted reserves, oil prices, and prices. All in logs, except interest rate.	1955:Q1–2000:Q4
Ramey (2011)	Not reported	SVAR	Defense news shocks	US	Defense news, log of real per capita government spending and GDP, interest rate, average marginal income tax rate, and one rotating variable.	1939:Q1–2008:Q4
Nakamura and Steinsson (2014)	Inflation is insignificant	Panel data regressions	Cross-state variation in military spending	US	Government spending and inflation	1969–2006
Dupor and Li (2015)	Prices decline or are insignificant	SVAR	Excess stock returns of military contractors	US	Accumulated excess returns, real government spending, real consumption, and prices. All in logs.	1951:M1–2002:M12

(*continued on next page*)

Table A.1 (*continued*).

Fiscal policy study	Response of prices/inflation	Method	Identification	Countries	Variables	Sample period
Ben Zeev and Pappa (2017)	Inflation increases	SVAR	Defense news (medium run restrictions)	US	Real per capita defense spending, output, hours, consumption, and investment, and real wages, average marginal tax rate, interest rate, inflation, TFP, Ramey (2011) news shocks, and Fisher and Peters (2010) defense shocks.	1947:Q1–2007:Q4
Ricco et al. (2016)	Inflation declines or is insignificant	Bayesian SVAR	Government spending news shocks	US	Fiscal news, GDP growth forecasts, fiscal policy disagreement index, government spending, marginal tax rate, consumption, GDP, interest rate, and one rotating variable, including inflation. All quantity variables in logs of real per capita levels.	1981:Q3–2012:Q4
D'Alessandro et al. (2019)	Inflation declines	Bayesian SVAR	Cholesky, Ramey (2011) defense news shocks	US	TFP, real per capita government spending, non-durable consumption, investment, GDP, and taxes, real wage, hours, interest rate and inflation. All in logs, except interest rate and inflation.	1954:Q3–2007:Q4
Ferrara et al. (2021)	Inflation increases	Bayesian Proxy-SVAR	Ramey (2011) defense news shocks	US	Real government spending, GDP, taxes, and consumption, inflation, TFP, trade balance, stock price of Boeing, and real exchange rate. All in logs, except inflation and the trade balance (pct. of GDP).	1964:Q1–2015:Q4, excl. 2007:Q3–2009:Q4

R_t: Nominal interest rate on 3-month Treasury Bills (TB3MS).

A_t: Raw Total Factor Productivity series constructed by the Federal Reserve Bank of San Francisco based on the methodology of Fernald (2014).[36]

w_t: Nonfarm Business Sector: Real Compensation Per Hour (COMPRNFB, Seasonally Adjusted, 2012=100).

The first four series are converted to per capita terms using the Census Bureau Civilian Population (All Ages) estimates, which we collect from the FRED database (POP), available from 1952 onwards (we take quarterly averages of monthly observations). Before 1952, we obtain annual data directly from the Census Bureau, and use linear interpolation to obtain quarterly observations. We take logs of all variables except the interest rate, R_t.

In addition, we use the following series from the FRED database for the robustness checks (taking logs of all variables except inflation expectations):

CPI index: Consumer Price Index for All Urban Consumers: All Items (CPIAUCSL, seasonally adjusted, 2012=100).

PCE Core index: Personal Consumption Expenditures Excluding Food and Energy Price Index (JCXFE, seasonally adjusted, 2012=100).

GDP deflator index: Gross Domestic Product: Implicit Price Deflator (GDPDEF, seasonally adjusted, 2012=100).

Commodity price index: Producer Price Index for All Commodities (PPIACO, not seasonally adjusted, 2012=100).

Productivity: Real Output per Hour of All Persons in the Nonfarm Business Sector (OPHNFB, seasonally adjusted, 2012=100).

Investment: Nonresidential Real Private Fixed Investment, quantity index (obtained directly from the Bureau of Economic Analysis, NIPA tables, Table 5.3.3., line 2). This series is converted to per capita terms as above.

Software Expenditure: Nonresidential Real Private Fixed Investment: Intellectual Property Products: Software, quantity index (obtained directly from the Bureau of Economic Analysis, NIPA tables, Table 5.3.3., line 17). This series is converted to per capita terms as above.

Inflation expectations: 1-year ahead inflation expectations from the Michigan Survey of Consumers. These can be obtained from https://data.sca.isr.umich.edu/data-archive/mine.php.

Finally, we use the following two series of "narrative" shocks to government spending:

FE_t: Forecast error of government spending. Following Auerbach and Gorodnichenko (2012), we compute this as the difference between forecasts of the growth rate of government spending (obtained from the Greenbook data of the Federal Reserve Board combined with the Survey of Professional Forecasters (SPF), using data from the SPF in overlapping observations) and the actual, first-release data for the growth rate of government spending from the Bureau of Economic Analysis.

NS_t: Defense news shocks series constructed by Ramey (2011) and obtained from the webpage of Valerie Ramey.

[36] The data can be collected from https://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp/.

Table C.1
Parameter estimates: Model with learning-by-doing.

Parameter	Description	Estimates	
		LBD restricted	LBD unrestricted
γ	Rotemberg price adj. costs	114.159 (171.499)	94.482 (75.681)
γ_W	Rotemberg wage adj. costs	618.712 (257.562)	144.175 (171.074)
δ	Capital depreciation rate	0.036 (0.136)	0.026 (0.066)
θ	Consumption habits	0.814 (19.987)	0.489 (1.288)
κ	Investment adj. costs	3.910 (10.882)	4.062 (4.510)
ρ_G	Persistence of spending shock	0.949 (0.008)	0.935 (0.009)
σ	Relative risk aversion	2.071 (196.191)	2.133 (5.440)
φ	Inverse Frisch elasticity	0.794 (4.683)	1.278 (8.584)
ϕ_π	Taylor coeff. on inflation	1.641 (7.733)	2.129 (2.717)
ϕ_y	Taylor coeff. on output gap	0.000 (0.100)	0.035 (0.214)
ρ_r	Interest rate smoothing	0.684 (2.554)	0.483 (0.559)
χ_2^K	Capital utilization adj. costs	8.000 (2144.935)	8.021 (2058.963)
χ_2	Tech. utilization adj. costs	N/A	N/A
χ_2^N	Labor utilization adj. costs	N/A	N/A
μ_N	Elasticity of skills to hours	0.111	1.357 (2.692)
ρ_X	Persistence of acquired skills	0.797	0.625 (1.335)

Notes: We report standard errors in brackets, obtained using the delta method.

Appendix C. Robustness checks

This appendix contains a series of robustness checks, as described in the main text. These are presented in Fig. C.1 to Fig. C.6 and Table C.1.

Appendix D. The model

This appendix presents the details of our model of variable technology utilization. We impose the functional form of $z\left(u_t\right)$ proposed in (26) throughout the appendix.

D.1. The steady state

The steady-state interest rate is pinned down by the inverse of the household's discount factor; $R = 1/\beta$. From the optimal price setting of intermediate goods firms (10), we obtain $mc = \frac{\varepsilon-1}{\varepsilon}$. From the goods market clearing condition (16), we get:

$$\frac{C}{Y} = 1 - \frac{g}{Y},$$

where $\frac{g}{Y}$ is determined exogenously. Steady-state production is pinned down from (6):

$$Y = uAN,$$

where A is exogenous, u is fixed at 1 in steady state, and N is fixed at $N = 0.25$. Combining labor supply (3) and labor demand (8) and using the production function, we can find the value of ψ that ensures this:

$$\begin{aligned}
\psi N^{\varphi} &= C_t^{-1} mc \frac{Y}{N} \Leftrightarrow \\
\psi N^{\varphi} &= C^{-1} mcuA \Leftrightarrow \\
\psi &= \frac{mcuA}{N^{\varphi} C}.
\end{aligned}$$

Finally, to ensure that the utilization rate equals 1 in steady state, we rewrite (9) to get:

$$\begin{aligned}
z'(1) &= mc\frac{Y}{u} \Leftrightarrow \\
\chi_1 &= mc\frac{Y}{u},
\end{aligned}$$

which pins down the required value of χ_1. This completes the characterization of the steady state.

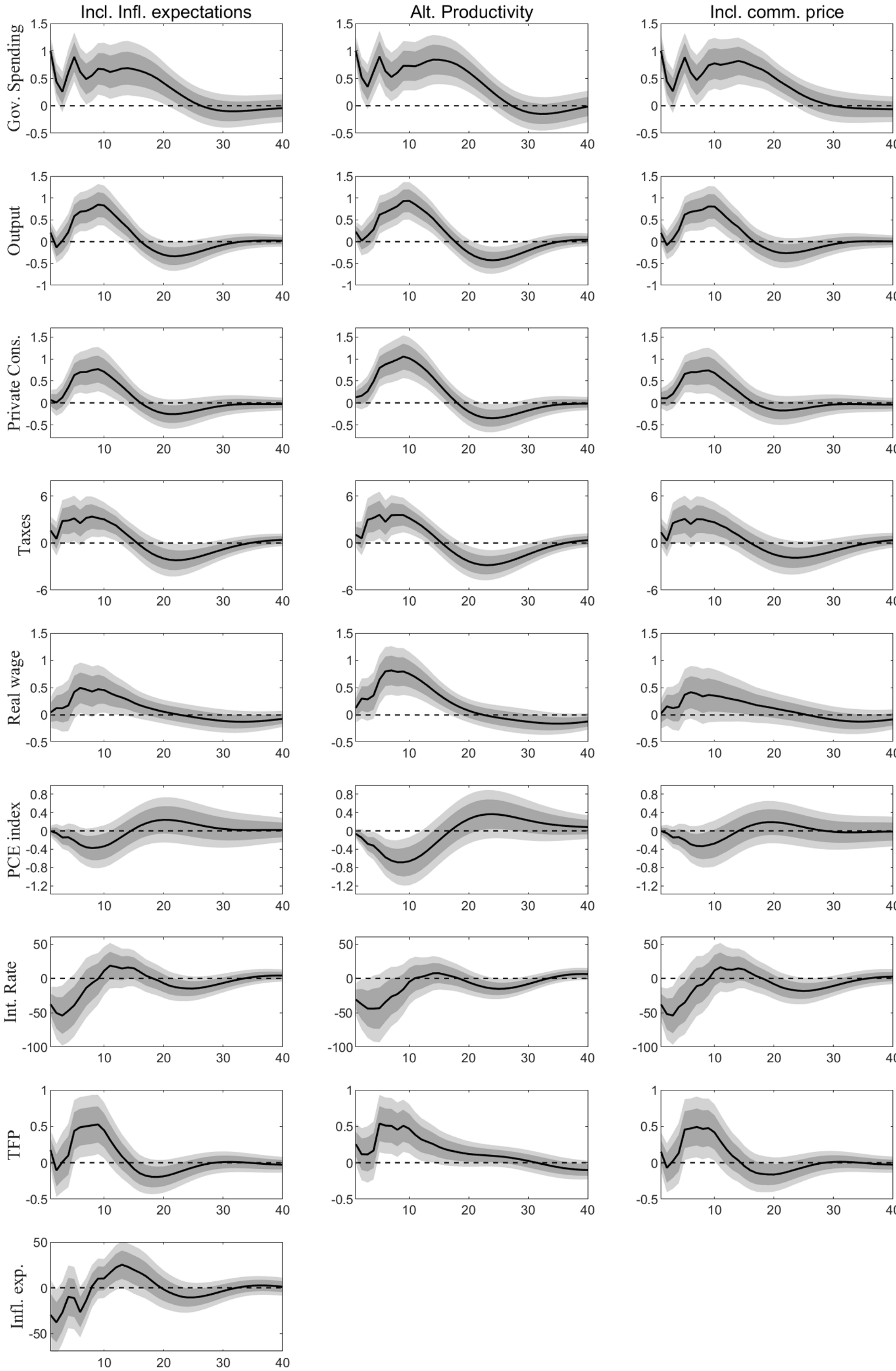

Fig. C.1. The dynamic effects of a shock to government spending. Robustness checks: Model augmented with inflation expectations (first column), alternative productivity measure (second column), including commodity prices (third column). The black line denotes the estimated response, while the gray areas represent the 68 percent confidence bands (dark gray) and the 90 percent confidence bands (light gray).

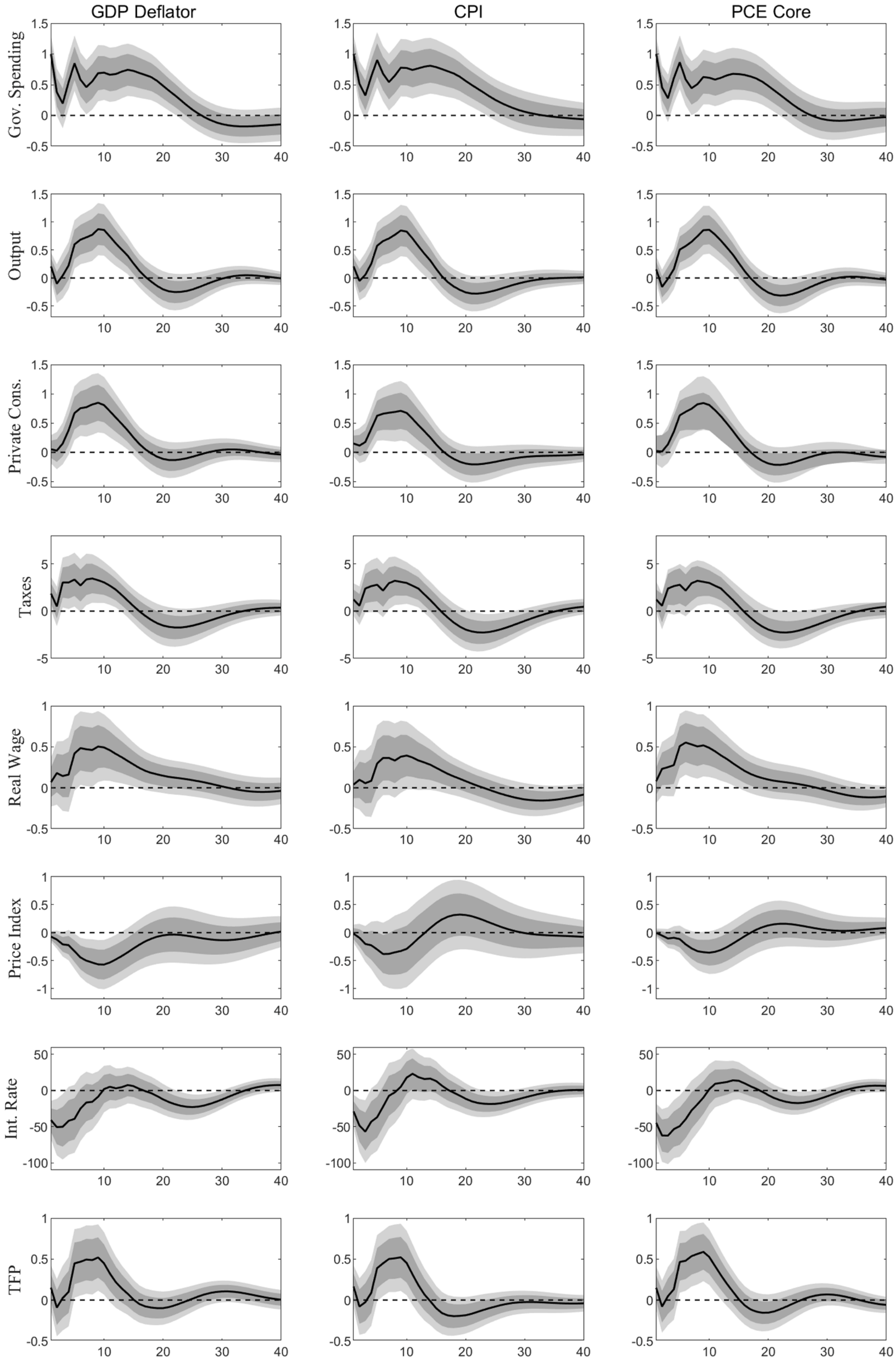

Fig. C.2. The dynamic effects of a shock to government spending. Robustness checks: Different price indices: GDP deflator (first column), CPI index (second column), PCE core price index (third column). The black line denotes the estimated response, while the gray areas represent the 68 percent confidence bands (dark gray) and the 90 percent confidence bands (light gray).

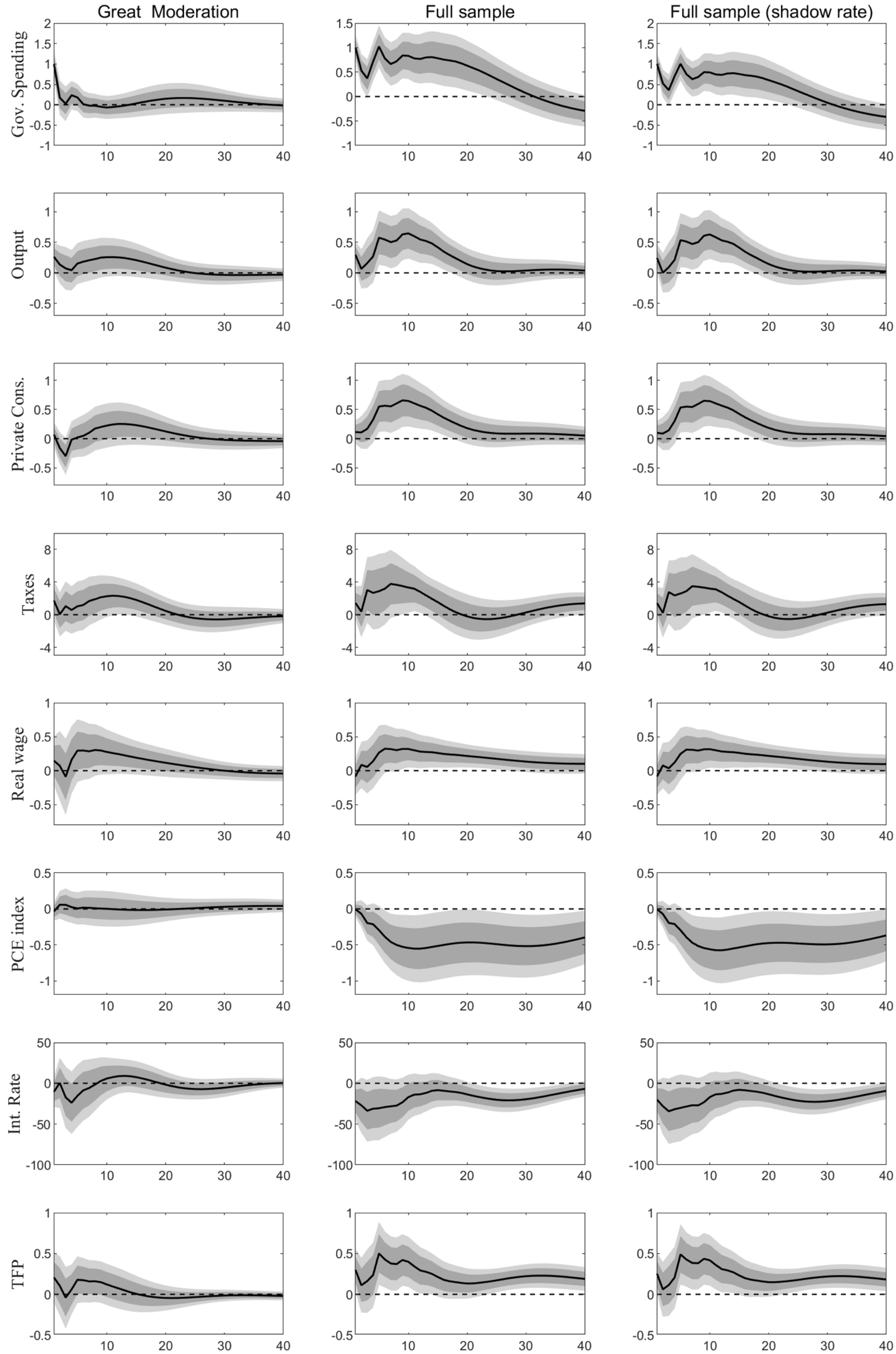

Fig. C.3. The dynamic effects of a shock to government spending. Robustness checks: Subsample stability for the period 1984:Q1-2008:Q3 (first column), 1966:Q4–2019:Q4 (second column), 1966:Q4–2019:Q4 using the shadow rate as interest rate measure (third column). The black line denotes the estimated response, while the gray areas represent the 68 percent confidence bands (dark gray) and the 90 percent confidence bands (light gray).

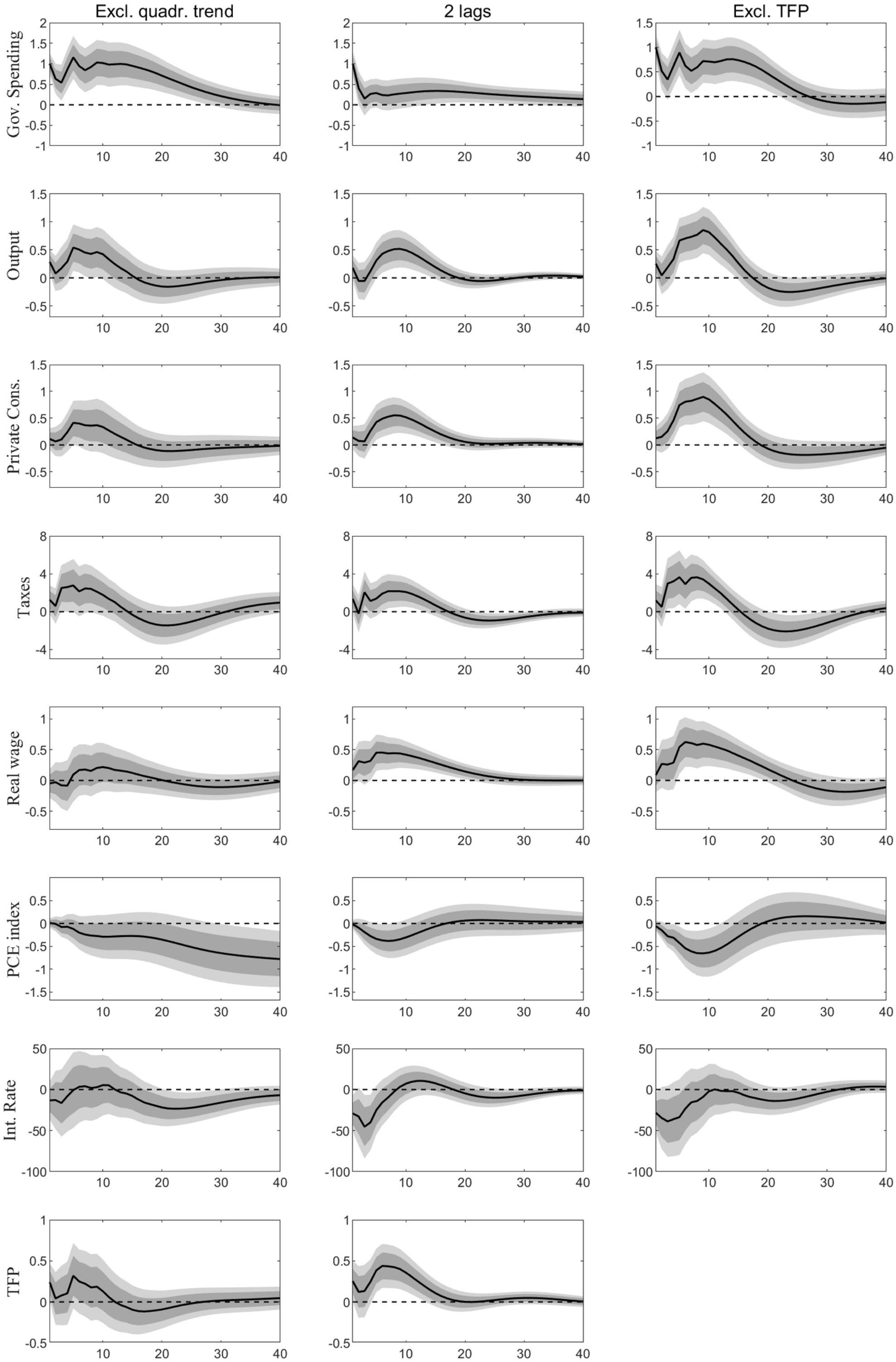

Fig. C.4. The dynamic effects of a shock to government spending. Robustness checks: Excluding quadratic time trend (first column), model with 2 lags instead of 4 (second column), model excluding TFP (third column). The black line denotes the estimated response, while the gray areas represent the 68 percent confidence bands (dark gray) and the 90 percent confidence bands (light gray).

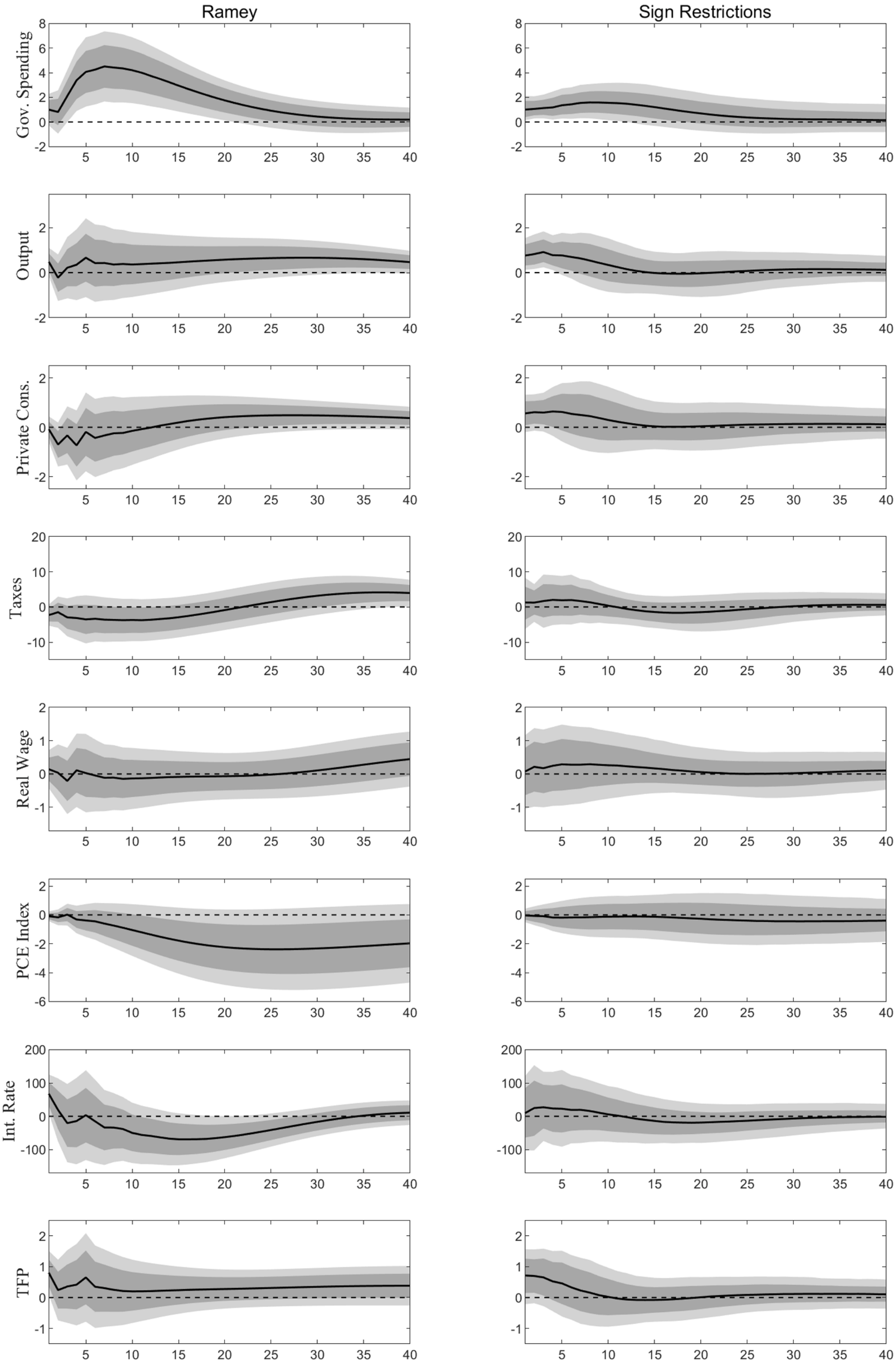

Fig. C.5. The dynamic effects of a shock to government spending. Left column: Estimates obtained using the identification scheme based on defense news shocks. Right column: Estimates obtained using sign restrictions. The black line denotes the estimated response, while the dark gray areas represent the 68 percent confidence bands (left column) or credible sets (right column) and the light gray areas represent the 90 percent confidence bands (left column) or credible sets (right column).

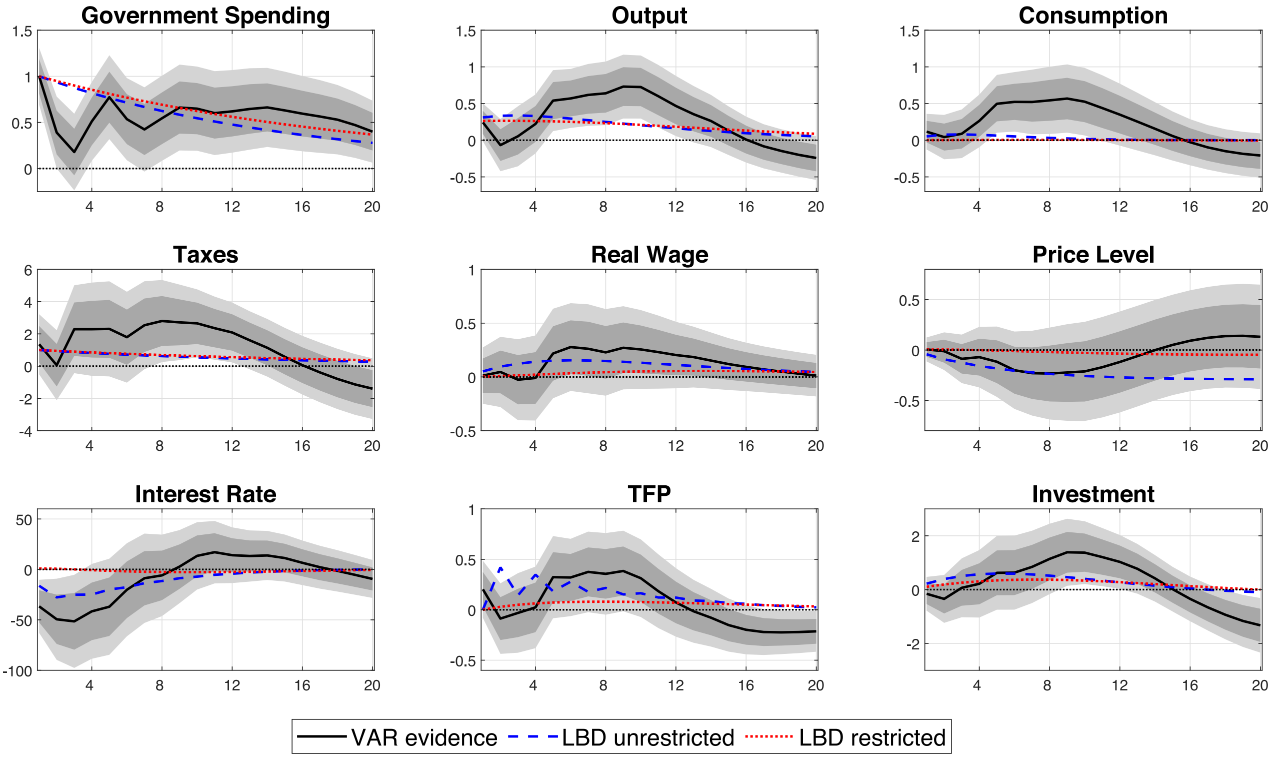

Fig. C.6. Impulse responses to a government spending shock of 1 percent. Solid black lines: estimated VAR model using the identification based on forecast errors. Gray areas: 68 percent confidence bands (dark gray) and 90 percent confidence bands (light gray) from the VAR model. Dashed blue lines: estimated baseline DSGE model with unrestricted learning-by-doing. Dashed red lines: estimated DSGE model with restricted learning-by-doing. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

D.2. Log-linearized model

We log-linearize the model around the non-stochastic steady state. Letting $\hat{x}_t$ denote the log deviation of a generic variable x_t from its steady-state value x, we obtain the following set of log-linearized equilibrium conditions:

$$\varphi \hat{N}_t = -\hat{C}_t + \hat{w}_t, \tag{D.1}$$

$$-\hat{C}_t = \mathrm{E}_t\left(-\hat{C}_{t+1} + \hat{R}_t - \hat{\pi}_{t+1}\right), \tag{D.2}$$

$$\hat{Y}_t = \hat{u}_t + \hat{N}_t, \tag{D.3}$$

$$\frac{C}{Y}\hat{C}_t = \hat{Y}_t - mc\hat{u}_t - \frac{g}{Y}\hat{g}_t, \tag{D.4}$$

$$\frac{\chi_2}{\chi_1}\hat{u}_t = \widehat{mc}_t + \hat{Y}_t - \hat{u}_t, \tag{D.5}$$

$$\widehat{mc}_t = \hat{w}_t - \hat{Y}_t + \hat{N}_t, \tag{D.6}$$

$$\hat{\pi}_t = \beta \mathrm{E}_t \hat{\pi}_{t+1} + \frac{\varepsilon - 1}{\gamma}\widehat{mc}_t, \tag{D.7}$$

$$\hat{g}_t = \rho_G \hat{g}_{t-1} + \varepsilon_t^G, \tag{D.8}$$

$$\hat{R}_t = \phi_\pi \hat{\pi}_t. \tag{D.9}$$

We thus have a system of 9 equations in 9 variables: $\hat{Y}_t, \hat{C}_t, \hat{g}_t, \hat{\pi}_t, \widehat{mc}_t, \hat{u}_t, \hat{w}_t, \hat{N}_t, \hat{R}_t$.

D.3. Analytical solution

As described in the main text, we derive the analytical solution to the model under the simplifying assumption of a unitary (inverse) Frisch elasticity of labor supply ($\varphi = 1$). It is straightforward to verify that (D.2) and (D.9) can be combined to obtain the Euler equation presented in Section 4:

$$-\hat{C}_t = \mathrm{E}_t\left(-\hat{C}_{t+1} + \phi_\pi \hat{\pi}_t - \hat{\pi}_{t+1}\right). \tag{D.10}$$

To arrive at the New Keynesian Phillips Curve studied in Section 4, we begin by combining (D.1) and (D.3) to obtain:

$$\hat{Y}_t = \hat{u}_t - \hat{C}_t + \hat{\omega}_t.$$

This expression can be inserted twice, into (D.4) and (D.5), to obtain:

$$\begin{aligned}\frac{C}{Y}\hat{C}_t &= \hat{u}_t - \hat{C}_t + \hat{\omega}_t - mc\hat{u}_t - \frac{g}{Y}\hat{g}_t \Leftrightarrow \\ \hat{\omega}_t &= \left(1 + \frac{C}{Y}\right)\hat{C}_t - (1 - mc)\hat{u}_t + \frac{g}{Y}\hat{g}_t,\end{aligned} \tag{D.11}$$

and

$$\begin{aligned}\frac{\chi_2}{\chi_1}\hat{u}_t &= \widehat{mc}_t + \hat{u}_t - \hat{C}_t + \hat{\omega}_t - \hat{u}_t \Leftrightarrow \\ \frac{\chi_2}{\chi_1}\hat{u}_t &= \hat{\omega}_t - \hat{Y}_t + \hat{N}_t + \hat{u}_t - \hat{C}_t + \hat{\omega}_t - \hat{u}_t \Leftrightarrow \\ \frac{\chi_2}{\chi_1}\hat{u}_t &= 2\hat{\omega}_t - \hat{u}_t - \hat{N}_t + \hat{N}_t - \hat{C}_t \Leftrightarrow \\ 2\hat{\omega}_t &= \left(\frac{\chi_2}{\chi_1} + 1\right)\hat{u}_t + \hat{C}_t,\end{aligned}$$

where we have used (D.3) and (D.6). We can now combine the two expressions obtained:

$$\left(1 + \frac{C}{Y}\right)\hat{C}_t - (1 - mc)\hat{u}_t + \frac{g}{Y}\hat{g}_t = \frac{\left(\frac{\chi_2}{\chi_1} + 1\right)\hat{u}_t + \hat{C}_t}{2} \Leftrightarrow$$

$$\hat{u}_t = \frac{\left(1 + \frac{2C}{Y}\right)}{\frac{\chi_2}{\chi_1} + 1 + 2(1 - mc)}\hat{C}_t + \frac{\frac{2g}{Y}}{\frac{\chi_2}{\chi_1} + 1 + 2(1 - mc)}\hat{g}_t. \tag{D.12}$$

We can now insert into the original New Keynesian Phillips Curve (D.7), using first (D.3) and (D.6):

$$\begin{aligned}\hat{\pi}_t &= \beta \mathrm{E}_t \hat{\pi}_{t+1} + \frac{\varepsilon - 1}{\gamma}\widehat{mc}_t \Leftrightarrow \\ \hat{\pi}_t &= \beta \mathrm{E}_t \hat{\pi}_{t+1} + \frac{\varepsilon - 1}{\gamma}\left(\hat{\omega}_t - \hat{Y}_t + \hat{N}_t\right) \Leftrightarrow \\ \hat{\pi}_t &= \beta \mathrm{E}_t \hat{\pi}_{t+1} + \frac{\varepsilon - 1}{\gamma}\left(\hat{\omega}_t - \hat{u}_t\right),\end{aligned}$$

and then inserting from (D.11):

$$\hat{\pi}_t = \beta \mathrm{E}_t \hat{\pi}_{t+1} + \frac{\varepsilon - 1}{\gamma}\left(\left(1 + \frac{C}{Y}\right)\hat{C}_t - (2 - mc)\hat{u}_t + \frac{g}{Y}\hat{g}_t\right),$$

where we can insert from (D.12) to get:

$$\begin{aligned}\hat{\pi}_t &= \beta \mathrm{E}_t \hat{\pi}_{t+1} + \frac{\varepsilon - 1}{\gamma}\left(\left(1 + \frac{C}{Y}\right)\hat{C}_t + \frac{g}{Y}\hat{g}_t\right) \\ &\quad - \frac{\varepsilon - 1}{\gamma}(2 - mc)\left[\frac{\left(1 + \frac{2C}{Y}\right)}{\frac{\chi_2}{\chi_1} + 1 + 2(1 - mc)}\hat{C}_t + \frac{\frac{2g}{Y}}{\frac{\chi_2}{\chi_1} + 1 + 2(1 - mc)}\hat{g}_t\right],\end{aligned}$$

which can be rewritten as:

$$\begin{aligned}\hat{\pi}_t &= \beta \mathrm{E}_t \hat{\pi}_{t+1} + \frac{\varepsilon - 1}{\gamma}\left(\frac{\frac{\chi_2}{\chi_1} + 1 + \left(\frac{\chi_2}{\chi_1} - 1\right)\frac{C}{Y} - mc}{\frac{\chi_2}{\chi_1} + 3 - 2mc}\hat{C}_t + \frac{\frac{g}{Y}\left(\frac{\chi_2}{\chi_1} - 1\right)}{\frac{\chi_2}{\chi_1} + 3 - 2mc}\hat{g}_t\right) \Leftrightarrow \\ \hat{\pi}_t &= \beta \mathrm{E}_t \hat{\pi}_{t+1} + a\hat{C}_t - b\hat{g}_t,\end{aligned} \tag{D.13}$$

after defining

$$a = \frac{\varepsilon - 1}{\gamma}\frac{\frac{\chi_2}{\chi_1} + 1 + \left(\frac{\chi_2}{\chi_1} - 1\right)\frac{C}{Y} - mc}{\frac{\chi_2}{\chi_1} + 3 - 2mc}, \tag{D.14}$$

$$b = \frac{\varepsilon-1}{\gamma}\frac{\frac{g}{Y}\left(1-\frac{\chi_2}{\chi_1}\right)}{\frac{\chi_2}{\chi_1}+3-2mc}. \tag{D.15}$$

Eqs. (D.10) and (D.13) can be combined with (D.8) to obtain 3 equations in $\hat{\pi}_t$, $\hat{C}_t$, and $\hat{g}_t$. We can solve this system analytically using the method of undetermined coefficients. For expositional simplicity, we assume that the shock to government spending has no persistence ($\rho_G = 0$). We conjecture that the solutions for $\hat{\pi}_t$ and $\hat{C}_t$ take the form:

$$\begin{aligned}\hat{C}_t &= \Psi\hat{g}_t,\\ \hat{\pi}_t &= \Phi\hat{g}_t,\end{aligned}$$

where the coefficients Ψ and Φ are yet to be determined. Inserting these conjectured solutions into (D.10) and (D.13), we obtain:

$$\begin{aligned}-\hat{C}_t &= \mathrm{E}_t\left(-\hat{C}_{t+1}+\phi_\pi\hat{\pi}_t-\hat{\pi}_{t+1}\right)\Leftrightarrow\\ -\Psi\hat{g}_t &= \mathrm{E}_t\left(-\Psi\hat{g}_{t+1}+\phi_\pi\Phi\hat{g}_t-\Phi\hat{g}_{t+1}\right)\Leftrightarrow\\ \Psi &= -\phi_\pi\Phi,\end{aligned}$$

where we have used that $\mathrm{E}_t\hat{g}_{t+1}=0$ when shocks have no persistence. Further, we get:

$$\begin{aligned}\hat{\pi}_t &= \beta\mathrm{E}_t\hat{\pi}_{t+1}+\frac{\varepsilon-1}{\gamma}\left(\frac{\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc}{\frac{\chi_2}{\chi_1}+3-2mc}\hat{C}_t+\frac{\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\chi_2}{\chi_1}+3-2mc}\hat{g}_t\right)\Leftrightarrow\\ \Phi\hat{g}_t &= \beta\mathrm{E}_t\Phi\hat{g}_{t+1}+\frac{\varepsilon-1}{\gamma}\left(\frac{\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc}{\frac{\chi_2}{\chi_1}+3-2mc}\Psi\hat{g}_t+\frac{\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\chi_2}{\chi_1}+3-2mc}\hat{g}_t\right)\Leftrightarrow\\ \Phi &= \frac{\varepsilon-1}{\gamma}\left(\frac{\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc}{\frac{\chi_2}{\chi_1}+3-2mc}\Psi+\frac{\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\chi_2}{\chi_1}+3-2mc}\right).\end{aligned}$$

Combining these two expressions yields:

$$\Phi = \frac{\varepsilon-1}{\gamma}\left(-\frac{\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc}{\frac{\chi_2}{\chi_1}+3-2mc}\phi_\pi\Phi+\frac{\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\chi_2}{\chi_1}+3-2mc}\right)\Leftrightarrow$$

$$\begin{aligned}\Phi\left[1+\frac{\varepsilon-1}{\gamma}\phi_\pi\frac{\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc}{\frac{\chi_2}{\chi_1}+3-2mc}\right] &= \frac{\varepsilon-1}{\gamma}\frac{\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\chi_2}{\chi_1}+3-2mc}\Leftrightarrow\\ \Phi\frac{\frac{\varepsilon-1}{\gamma}\phi_\pi\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]+\frac{\chi_2}{\chi_1}+3-2mc}{\frac{\chi_2}{\chi_1}+3-2mc} &= \frac{\varepsilon-1}{\gamma}\frac{\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\chi_2}{\chi_1}+3-2mc}\Leftrightarrow\end{aligned}$$

$$\Phi = \frac{\frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\varepsilon-1}{\gamma}\phi_\pi\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]+\frac{\chi_2}{\chi_1}+3-2mc},$$

and then:

$$\begin{aligned}\Psi &= -\phi_\pi\Phi\Leftrightarrow\\ \Psi &= -\frac{\phi_\pi\frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\varepsilon-1}{\gamma}\phi_\pi\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]+\frac{\chi_2}{\chi_1}+3-2mc},\end{aligned}$$

so that the solution is:

$$\hat{C}_t = -\frac{\phi_\pi\frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\varepsilon-1}{\gamma}\phi_\pi\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]+\frac{\chi_2}{\chi_1}+3-2mc}\hat{g}_t, \tag{D.16}$$

$$\hat{\pi}_t = \frac{\frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\frac{\varepsilon-1}{\gamma}\phi_\pi\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]+\frac{\chi_2}{\chi_1}+3-2mc}\hat{g}_t. \tag{D.17}$$

This confirms the form of our conjectured solution, and provides us with closed-form expressions of how consumption and inflation react to a government spending shock on impact. To establish the sign of these coefficients, we first note that the denominator is positive whenever:

$$\frac{\varepsilon-1}{\gamma}\phi_\pi\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]+\frac{\chi_2}{\chi_1}+3-2mc>0 \Leftrightarrow$$

$$\frac{\chi_2}{\chi_1}\left[1+\frac{\varepsilon-1}{\gamma}\phi_\pi\left(1+\frac{C}{Y}\right)\right]>mc\left(2+\phi_\pi\frac{\varepsilon-1}{\gamma}\right)-3-\frac{\varepsilon-1}{\gamma}\phi_\pi\left(1-\frac{C}{Y}\right)\Leftrightarrow$$

$$\chi_2>\chi_1\frac{mc\left(2+\phi_\pi\frac{\varepsilon-1}{\gamma}\right)-3-\frac{\varepsilon-1}{\gamma}\phi_\pi\left(1-\frac{C}{Y}\right)}{1+\frac{\varepsilon-1}{\gamma}\phi_\pi\left(1+\frac{C}{Y}\right)}. \tag{D.18}$$

This is a lower bound on χ_2. We show below that this condition is always satisfied when the model has a unique and determinate solution. We therefore obtain a decline in inflation and an increase in consumption if and only if the numerators in both expressions are negative:

$$\phi_\pi\frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)<0\Leftrightarrow$$

$$\left(\frac{\chi_2}{\chi_1}-1\right)<0\Leftrightarrow$$

$$\chi_2<\chi_1. \tag{D.19}$$

This is the condition stated in Proposition 2 in the main text. However, to complete the proof, the next subsection derives the conditions for the model to have a unique and stable equilibrium.

D.4. Equilibrium determinacy and uniqueness

The system consisting of (D.10) and (D.13) has two non-predetermined variables. This implies that a necessary and sufficient condition for the model to have a unique and determinate equilibrium is that both eigenvalues of the characteristic polynomial should be inside the unit circle. To write up the characteristic polynomial, we first restate the system on matrix form. After some algebra, we arrive at the following expression:

$$\begin{bmatrix}\widehat{C}_t\\ \widehat{\pi}_t\end{bmatrix}=\Omega\begin{bmatrix}\Upsilon & (1-\beta\phi_\pi)\Upsilon\\ \Gamma & \Gamma+\beta\Upsilon\end{bmatrix}\begin{bmatrix}E_t\widehat{C}_{t+1}\\ E_t\widehat{\pi}_{t+1}\end{bmatrix}+\Omega\Xi\begin{bmatrix}-\phi_\pi\\ 1\end{bmatrix}\widehat{g}_t\Leftrightarrow$$

$$\begin{bmatrix}\widehat{C}_t\\ \widehat{\pi}_t\end{bmatrix}=A_0\begin{bmatrix}E_t\widehat{C}_{t+1}\\ E_t\widehat{\pi}_{t+1}\end{bmatrix}+B_0\widehat{g}_t,\quad A_0\equiv\Omega\begin{bmatrix}\Upsilon & (1-\beta\phi_\pi)\Upsilon\\ \Gamma & \Gamma+\beta\Upsilon\end{bmatrix},\quad B_0\equiv\Omega\Xi\begin{bmatrix}\phi_\pi\\ 1,\end{bmatrix}$$

where we have defined:

$$\Omega\equiv\frac{1}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]},$$

$$\Gamma\equiv\frac{\varepsilon-1}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right],$$

$$\Xi\equiv\frac{\varepsilon-1}{\gamma}\left(\frac{\chi_2}{\chi_1}-1\right)\frac{g}{Y},$$

$$\Upsilon\equiv\left(\frac{\chi_2}{\chi_1}+3-2mc\right).$$

The characteristic polynomial is then:

$$\left|A_0-\lambda I\right|=0\Leftrightarrow$$

$$\left|\Omega\begin{bmatrix}\Upsilon & (1-\beta\phi_\pi)\Upsilon\\ \Gamma & \Gamma+\beta\Upsilon\end{bmatrix}-\lambda\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\right|=0\Leftrightarrow$$

$$0=\left|\begin{bmatrix}\frac{\left(\frac{\chi_2}{\chi_1}+3-2mc\right)}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}-\lambda & \frac{(1-\beta\phi_\pi)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}\\ \frac{\frac{\varepsilon-1}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]} & \frac{\frac{\varepsilon-1}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]+\beta\left(\frac{\chi_2}{\chi_1}+3-2mc\right)}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}-\lambda\end{bmatrix}\right|.$$

After some tedious algebra, we are able to restate the implied second-order polynomial as:

$$0=\lambda^2+a_1\lambda+a_0,$$

where we have defined:

$$a_1 \equiv -\frac{(1+\beta)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\varepsilon-1}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]},$$

$$a_0 \equiv \frac{\beta\left(\frac{\chi_2}{\chi_1}+3-2mc\right)}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}.$$

We know that both eigenvalues are inside the unit circle if and only if both of the following conditions are satisfied:

$$|a_0| < 1, \tag{D.20}$$

$$|a_1| < 1 + a_0. \tag{D.21}$$

We can check these in turn. The first condition yields:

$$\left|\frac{\beta\left(\frac{\chi_2}{\chi_1}+3-2mc\right)}{\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}\right| < 1.$$

Since $\beta < 1$ and the bracket in the numerator is always positive, the denominator will be larger than the numerator (and thus, the inequality satisfied) as long as the second term in the denominator is positive:

$$\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right] > 0 \Leftrightarrow$$

$$\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\left(1-\frac{g}{Y}\right)-mc > 0 \Leftrightarrow$$

$$\frac{\chi_2}{\chi_1}\left(1+\left(1-\frac{g}{Y}\right)\right) > mc+\left(1-\frac{g}{Y}\right)-1 \Leftrightarrow$$

$$\frac{\chi_2}{\chi_1} > \frac{mc-\frac{g}{Y}}{2-\frac{g}{Y}}. \tag{D.22}$$

This is the condition stated in Proposition 1 in the main text, providing another lower bound on χ_2. We can verify that this is the relevant, binding lower bound on χ_2 by showing that this expression is strictly larger than the one implied by (D.18):

$$\chi_1\frac{mc-\frac{g}{Y}}{2-\frac{g}{Y}} > \chi_1\frac{mc\left(2+\phi_\pi\frac{\varepsilon-1}{\gamma}\right)-3-\frac{\varepsilon-1}{\gamma}\phi_\pi\left(1-\frac{C}{Y}\right)}{1+\frac{\varepsilon-1}{\gamma}\phi_\pi\left(1+\frac{C}{Y}\right)} \Leftrightarrow$$

$$\left(mc-\frac{g}{Y}\right)\left[1+\frac{\varepsilon-1}{\gamma}\phi_\pi\left(1+\frac{C}{Y}\right)\right] > \left(2-\frac{g}{Y}\right)\left[mc\left(2+\phi_\pi\frac{\varepsilon-1}{\gamma}\right)-3-\frac{\varepsilon-1}{\gamma}\phi_\pi\left(1-\frac{C}{Y}\right)\right] \Leftrightarrow$$

$$6 > 2\frac{g}{Y}(2-mc)+3mc,$$

where the last step follows from some simple but tedious algebra. The right-hand side is maximized when $\frac{g}{Y}$ reaches its upper bound of 1 and mc reaches its upper bound of 1 (when $\varepsilon \to \infty$). In this case, the right-hand side approaches 5. We can thus conclude that this condition is always satisfied, so that the binding lower bound on χ_2 is given from (D.22).

Consider now the second necessary and sufficient condition for a unique and determinate equilibrium, (D.21), which yields:

$$|a_1| < 1 + a_0 \Leftrightarrow$$

$$\left|-\frac{(1+\beta)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\varepsilon-1}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}\right| <$$

$$1+\frac{\beta\left(\frac{\chi_2}{\chi_1}+3-2mc\right)}{\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]} \Leftrightarrow$$

$$\left|-\frac{(1+\beta)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\varepsilon-1}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}{\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}\right| <$$

$$\frac{\beta\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\chi_2}{\chi_1}+3-2mc+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}{\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}.$$

We saw above that the last term in the denominator is positive, and we have established that also the first term is positive, so we can cancel out the denominators:

$$\left| -\left[(1+\beta)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\varepsilon-1}{\gamma}\left(\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right)\right]\right| <$$
$$(1+\beta)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right].$$

Using the same insights, we conclude that all terms on the left-hand side must be positive, so taking absolute values yields:

$$(1+\beta)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\varepsilon-1}{\gamma}\left(\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right) <$$
$$(1+\beta)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)+\frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right] \Leftrightarrow$$
$$\frac{\varepsilon-1}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right] < \frac{\phi_\pi(\varepsilon-1)}{\gamma}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right] \Leftrightarrow$$

$$\phi_\pi > 1, \tag{D.23}$$

which is just the well-known Taylor-principle (in the absence of a monetary policy reaction to output, as assumed above). This condition is satisfied by assumption, as we have assumed $\phi_\pi > 1$ already in the main text.

To sum up, we have established that the model has a unique and determinate solution if and only if conditions (D.22) and (D.23) are satisfied, and that when this is the case, the solution features an increase in consumption and a decline in inflation if and only if condition (D.19) holds. This completes the proof of Propositions 1 and 2 in the main text. ■

As a final note, recall our graphical representation of Eqs. (D.10) and (D.13) in Section 4. Given the definition of the parameters a and b in (D.14) and (D.15), it is easy to verify that the condition for the parameter a to be positive, and thus for the rewritten New Keynesian Phillips Curve (D.13) to be upward-sloping, is identical to the condition in (D.22). Likewise, it can be easily verified that the parameter b is positive, so that a government spending shock shifts this curve down, if and only if the condition given by (D.19) is satisfied.

D.5. Detour: the basic New Keynesian model

In this subsection, we derive the solution to a model version *without* variable technology utilization. Incidentally, in this case the model collapses to the basic New Keynesian model, as presented, e.g., in Galí (2015), augmented with government spending. For comparison, we make the same assumptions as in the simplified version of our baseline model: Constant technology, constant returns to scale in production, log utility in consumption, unitary (inverse) Frisch elasticity of labor supply, no monetary policy reaction to the output gap, and no persistence in fiscal policy shocks. Under these assumptions, the basic New Keynesian model is given by the following set of equations:

$$\hat{N}_t = -\hat{C}_t + \hat{\omega}_t,$$

$$-\hat{C}_t = \mathrm{E}_t\left(-\hat{C}_{t+1} + \hat{R}_t - \hat{\pi}_{t+1}\right),$$

$$\hat{Y}_t = \hat{N}_t,$$

$$\frac{C}{Y}\hat{C}_t = \hat{Y}_t - \frac{g}{Y}\hat{g}_t,$$

$$\widehat{mc}_t = \hat{\omega}_t,$$

$$\hat{\pi}_t = \beta \mathrm{E}_t\hat{\pi}_{t+1} + \frac{\varepsilon-1}{\gamma}\widehat{mc}_t,$$

$$\hat{R}_t = \phi_\pi\hat{\pi}_t,$$

plus an exogenous process for $\hat{g}_t$. We can combine these equations to obtain:[37]

$$\hat{\pi}_t = \beta \mathrm{E}_t\hat{\pi}_{t+1} + \frac{\varepsilon-1}{\gamma}\left(\hat{C}_t\left(1+\frac{C}{Y}\right)+\frac{g}{Y}\hat{g}_t\right),$$
$$-\hat{C}_t = \mathrm{E}_t\left(-\hat{C}_{t+1} + \phi_\pi\hat{\pi}_t - \hat{\pi}_{t+1}\right).$$

[37] Having carefully described the analytical solution to our baseline model above, we do not present any intermediate steps in this subsection, but simply state the results.

From these expressions, it follows directly—as argued in Section 4—that this model version also implies a downward-sloping Euler equation in $(\hat{C}_t, \hat{\pi}_t)$-space, and an upward-sloping NKPC-curve. Importantly, a positive shock to government spending shifts the NKPC-curve *up*, unlike our model of variable technology utilization, see Fig. 3. Following the same steps as in the preceding subsections, we can derive the solution to this model, which is given by:

$$\hat{C}_t = -\frac{\phi_\pi \frac{\varepsilon-1}{\gamma}\frac{g}{Y}}{\frac{\varepsilon-1}{\gamma}\phi_\pi\left(2-\frac{g}{Y}\right)+1}\hat{g}_t, \tag{D.24}$$

$$\hat{\pi}_t = \frac{\frac{\varepsilon-1}{\gamma}\frac{g}{Y}}{\frac{\varepsilon-1}{\gamma}\phi_\pi\left(2-\frac{g}{Y}\right)+1}\hat{g}_t. \tag{D.25}$$

Both the numerator and denominator of both expressions are necessarily positive. An increase in $\hat{g}_t$ thus leads to an increase in inflation and a decline in consumption in this model, in contrast to our baseline model studied above.

Finally, we can verify that the solution to our baseline model collapses to that of the simple New Keynesian model when the adjustment costs associated with changes in technology utilization become sufficiently high. This can be seen by rewriting the solution given by (D.16) and (D.17) as:

$$\hat{C}_t = -\frac{\phi_\pi \frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(1-\frac{\chi_1}{\chi_2}\right)}{\frac{\varepsilon-1}{\gamma}\phi_\pi\left[1+\frac{\chi_1}{\chi_2}+\left(1-\frac{\chi_1}{\chi_2}\right)\frac{C}{Y}-\frac{\chi_1}{\chi_2}mc\right]+1+(3-2mc)\frac{\chi_1}{\chi_2}}\hat{g}_t,$$

$$\hat{\pi}_t = \frac{\frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(1-\frac{\chi_1}{\chi_2}\right)}{\frac{\varepsilon-1}{\gamma}\phi_\pi\left[1+\frac{\chi_1}{\chi_2}+\left(1-\frac{\chi_1}{\chi_2}\right)\frac{C}{Y}-\frac{\chi_1}{\chi_2}mc\right]+1+(3-2mc)\frac{\chi_1}{\chi_2}}\hat{g}_t,$$

and letting $\chi_2 \to \infty$, in which case these expressions collapse to those presented in (D.24) and (D.25).

Appendix E. Government spending shocks in a calibrated model

In this Appendix, we use model simulations to study the effects of a government spending shock. To this end, we assign realistic values to all parameters of the model, and study the implied impulse responses. We also offer a set of sensitivity checks regarding certain key parameters. With respect to the simple model presented in Section 3, we now relax the assumptions of log utility in consumption, constant returns to scale in production, and no monetary policy response to the output gap. This means that Eqs. (2), (6), and (13) are replaced by, respectively:

$$U_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{\psi N_t^{1+\varphi}}{1+\varphi}, \tag{E.1}$$

$$Y_{i,t} = V_{i,t} N_{i,t}^{1-\alpha}, \tag{E.2}$$

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi}\left(\frac{Y_t}{Y}\right)^{\phi_y}, \tag{E.3}$$

where $\sigma > 0$, $\sigma \neq 1$, $0 \leq \alpha < 1$, and $\phi_y \geq 0$. As a consequence, the first-order conditions (3), (4), and (8) are changed to:

$$\psi N_t^{\varphi} = w_t C_t^{-\sigma},$$

$$C_t^{-\sigma} = \beta \mathrm{E}_t \frac{R_t C_{t+1}^{-\sigma}}{\pi_{t+1}},$$

$$w_t = (1-\alpha)\, mc_{i,t} \frac{Y_{i,t}}{N_{i,t}}.$$

E.1. Calibration

The baseline calibration of the model is as follows: We set $\beta = 0.99$, implying an annualized real interest rate of 4% in steady state. The coefficient of relative risk aversion is set to $\sigma = 2$, in line with microeconometric estimates (see, e.g., Attanasio and Weber, 1995). As in Christiano et al. (2005), we maintain the assumption from Section 4 of an (inverse) Frisch elasticity of labor supply of unity; $\varphi = 1$. The weight on disutility of labor hours in the utility function, ψ, is calibrated so that $N = 1/4$ (this only affects the scale of the economy). On the production side, we follow most of the literature and set $\varepsilon = 6$, implying a steady-state markup of 20 percent. We maintain the assumption of constant returns to scale ($\alpha = 0$) in our baseline analysis, and then study the case of decreasing returns to scale in Appendix E.3.3. The adjustment cost associated with price changes is calibrated so that a given price is changed, on average, every 3 quarters, consistent with microeconometric evidence reported by Nakamura and Steinsson (2008). Given the other parameters, this implies a value of $\gamma = 29.41$.

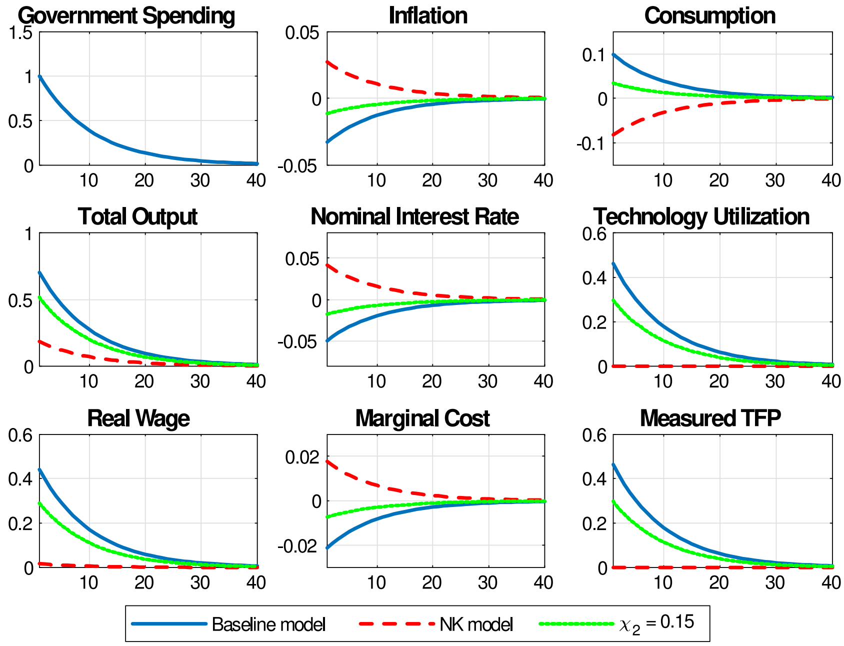

Fig. E.1. Impulse responses of key variables to a positive government spending shock of 1 percent. Solid blue lines: baseline model with $\chi_2 = 0.1$. Dashed red lines: model without variable technology utilization (obtained by setting $\chi_2 = 100$). Dotted green lines: baseline model with alternative value of $\chi_2 = 0.15$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Regarding the policy-related parameters, we follow most of the literature in setting the steady-state inflation rate to zero. The response of monetary policy to movements in inflation is set to a standard value of $\phi_\pi = 1.5$. We initially set the output response to zero, $\phi_y = 0$, and then "switch on" this reaction when studying the role of monetary policy in Appendix E.3.2. The persistence of government spending shocks is set to $\rho_G = 0.9$, in line with Galí et al. (2007). The ratio of government spending to output in the model matches the sample average in the data for the period 1960–2017, which equals $\frac{g}{Y} = 0.25$.

Conditional on our baseline calibration of all other parameters, the admissible range of values for χ_2 established analytically in Section 4 implies that for any value of $\chi_2 \in [0.07, 0.21]$, we obtain impact effects of inflation and consumption in line with the data. In the simulations below, we pick a baseline value of $\chi_2 = 0.1$, while our robustness checks shed more light on the quantitative importance of this parameter.

E.2. Impulse-response analysis

Given our baseline calibration, Fig. E.1 displays the impulse responses of the model to a government spending shock of 1 percent (solid blue lines), along with the responses of a basic New Keynesian model without variable technology utilization (dashed red lines). As the figure illustrates, our baseline model implies an increase in the rate of technology utilization in response to the shock. This is sufficient to generate a decline in marginal costs, despite the increase in the wage rate. As a consequence, inflation drops. This leads to a reduction in the nominal interest rate, reducing also the real rate. In line with the intuition traced out in Section 4, consumption therefore increases, in turn amplifying the increase in total output. Note that the responses of the real wage and the nominal interest rate are in line with the empirical evidence from Section 2. Also in line with the data, we observe an increase in "Measured TFP" as given by the *utilized* technology level, V_t. In the absence of exogenous technology shocks, this variable moves one-for-one with the utilization rate. In contrast, measured TFP remains constant in the model without variable technology utilization. In that case marginal costs increase in response to the shock, generating an increase in inflation and the nominal interest rate, and a drop in consumption, in contrast to our empirical evidence. The impact multiplier of government spending on total value added (defined as the sum of private and public consumption) is substantially higher in our baseline model (1.30) than in the model without variable technology utilization (0.75).

E.3. Sensitivity analysis

This subsection explores the robustness of our findings with respect to some of our key parameter values and modeling choices.

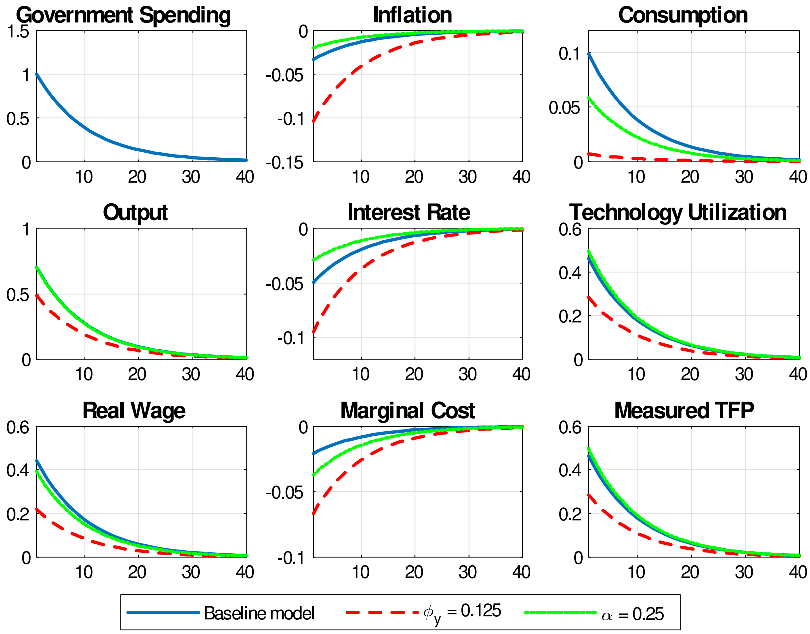

Fig. E.2. Impulse responses of key variables to a positive government spending shock of 1 percent. Solid blue lines: baseline model with no monetary policy reaction to output fluctuations ($\phi_y = 0$) and constant returns to scale ($\alpha = 0$). Dashed red lines: alternative model with monetary policy reaction to output ($\phi_y = 0.125$). Dotted green lines: alternative model with decreasing returns to scale ($\alpha = 0.25$). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

E.3.1. Movements in the technology utilization rate

Given the uncertainty surrounding the cost of changing the rate of technology utilization, it is worth pointing out that we do not require dramatic changes in the utilization rate to obtain a decline in inflation: Under our baseline calibration, the utilization rate increases by less than 0.5 percent; somewhat less than the increase in output. To shed some light on the robustness of our findings, the dotted green lines in Fig. E.1 show the corresponding impulse responses after changing the value of χ_2 from 0.1 to 0.15. In this case, the utilization rate increases only by around 0.3 percent on impact. Yet, inflation and consumption still behave in accordance with the empirical evidence, but now display much smaller changes. This shows that even relatively small movements in the utilization rate are sufficient to obtain the desired responses from the model.

E.3.2. The role of monetary policy

The stance of monetary policy plays a key role in the transmission of fiscal policy. At the heart of the negative relationship between inflation and consumption implied by our baseline model are movements in the real interest rate: In the simplified model version studied in Section 4, consumption increases if and only if the central bank engineers a decline in the real interest rate upon observing a drop in inflation. This, in turn, requires a sufficiently strong reaction of the nominal policy rate to a given change in inflation. When we allow for a monetary policy reaction to output fluctuations, this direct link between consumption and inflation breaks down. In terms of the graphical representation in Fig. 3, the (EE)-curve becomes steeper and is shifted down in response to a positive government spending shock. With this in mind, we should expect a smaller increase—or even a decline—in consumption, and a larger drop in inflation. Fig. E.2 confirms this intuition: The dashed red lines report impulse responses from a version of our model featuring a non-zero policy reaction to output, where we set $\phi_y = 0.125$ (0.5 divided by 4). In this case, we observe a very small increase in consumption, but a much larger decline in inflation, as compared to our baseline model (solid blue lines).

We can elaborate further by characterizing numerically the requirements that monetary policy must meet in order for our model to match, at least from a qualitative viewpoint, the empirical evidence. Fig. E.3 shows the behavior of our model as a function of the parameters in the monetary policy rule (13), keeping all other parameters at their baseline calibration. For low values of ϕ_π and ϕ_y, as illustrated by the blue area, the model does not have a unique and stable equilibrium given our baseline calibration.[38] As also shown analytically in Appendix D.4, a version of the Taylor principle of standard New Keynesian models holds up in our model: To ensure a unique and stable solution, monetary policy must be sufficiently responsive to movements in inflation. When this condition is satisfied, the ratio $\frac{\phi_\pi}{\phi_y}$ must be sufficiently high to ensure that the model produces the desired responses. The green area indicates combinations of policy parameters for which the model produces an increase in consumption and a decline in inflation on impact,

[38] For a given combination of ϕ_π and ϕ_y, there may exist different combinations of the other parameters of the model (in particular χ_2) for which a unique, stable solution is restored, cf. the discussion in Section 4.

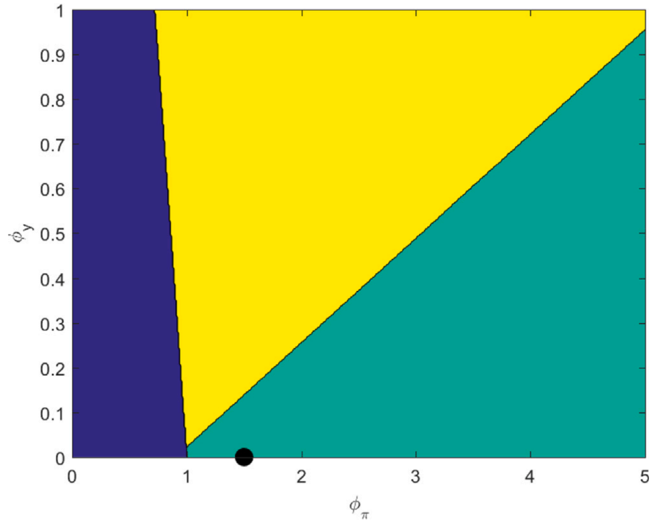

Fig. E.3. Model outcomes for different combinations of monetary policy parameters. Blue area: No unique and determinate solution. Yellow area: The model fails to generate a decline in inflation and/or an increase in consumption on impact. Green area: The model generates a decline in inflation and an increase in consumption on impact. The black dot indicates our baseline calibration. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

while the yellow area indicates combinations where either of these does not obtain. The black dot denotes our baseline calibration. For relatively high values of ϕ_π, the decline in inflation associated with an increase in government spending leads to a reduction in the nominal and real interest rate, and thus an increase in consumption. Given the empirical evidence presented in Section 2, this case appears to be the most realistic.

E.3.3. Decreasing returns to scale

So far in our analysis, we have assumed a constant-returns-to-scale technology in the intermediate goods sector. This assumption facilitates a decline in inflation. If instead there are decreasing returns to scale ($\alpha > 0$), a given increase in production requires a larger increase in labor inputs, thus driving up marginal costs, which—all else equal—makes it harder to observe a decline in marginal costs in equilibrium. It is therefore important to verify that our proposed mechanism can reproduce the empirical evidence even in the case of decreasing returns to scale. To this end, the dotted green lines in Fig. E.2 show impulse responses from our model under the assumption that $\alpha = 0.25$, as in Galí (2015), while the solid blue lines display our benchmark model for comparison.[39] As can be seen, our main findings are confirmed, as the model is still able to generate a drop in inflation alongside an increase in consumption. However, from a quantitative viewpoint, the movements in these variables are somewhat smaller than those observed in our baseline model, reflecting that our mechanism of variable technology adoption has less quantitative bite in this case.

Appendix F. Details of the extended model with capital formation

We first state the first-order conditions of the extended model, beginning with those of the household. The first-order conditions for the choices of consumption and bond holdings can be stated as:

$$\lambda_t = \left(C_t - \theta C_{t-1}\right)^{-\sigma} - \beta\theta\left(\mathrm{E}_t C_{t+1} - \theta C_t\right)^{-\sigma}, \tag{F.1}$$

$$\lambda_t = \beta \mathrm{E}_t \frac{R_t \lambda_{t+1}}{\pi_{t+1}}, \tag{F.2}$$

with λ_t denoting the multiplier associated with (22). The household also chooses investment and capital subject to (21) and (22). The relevant first-order conditions can be written as:

$$\begin{aligned} 1 = {} & Q_t\left(1 - \frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \kappa\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right) \\ & + \beta\kappa \mathrm{E}_t\left[\frac{Q_{t+1}\lambda_{t+1}}{\lambda_t}\left(\frac{I_{t+1}}{I_t} - 1\right)\frac{I_{t+1}^2}{I_t^2}\right], \end{aligned} \tag{F.3}$$

[39] In this experiment, we have again set $\phi_y = 0$ as in the baseline model. The calibrated parameters ψ, γ, and χ_1 are automatically adjusted so as to ensure that our calibration targets are maintained.

$$\beta \mathrm{E}_t \left\{ \lambda_{t+1} \left[r^K_{t+1} u^K_{t+1} - z^K \left(u^K_{t+1} \right) + (1-\delta) Q_{t+1} \right] \right\} = \lambda_t Q_t, \tag{F.4}$$

where Q_t denotes the price of installed capital (in units of consumption), which is given by $Q_t \equiv \frac{\mu_t}{\lambda_t}$, where μ_t is the multiplier associated with (21). The first-order condition for capital utilization is simply:

$$r^K_t = z^{K\prime} \left(u^K_t \right). \tag{F.5}$$

Finally, the household now chooses the wage rate that maximizes utility subject to (19) and (22). The resulting first-order condition can be stated (after imposing a symmetric equilibrium in which all households set the same wage rate) as:

$$\begin{aligned} 0 &= \psi \varepsilon_W N_t^{1+\varphi} + \left(1-\varepsilon_W\right) \lambda_t w_t N_t \\ &\quad - \gamma_W \left(\pi^W_t - 1 \right) \lambda_t Y_t \pi^W_t + \beta \gamma_W \left(\mathrm{E}_t \pi^W_{t+1} - 1 \right) \mathrm{E}_t \left[\lambda_{t+1} Y_{t+1} \pi^W_{t+1} \right], \end{aligned} \tag{F.6}$$

where $\pi^W_t \equiv \frac{W_t}{W_{t-1}}$ denotes wage inflation. Log-linearizing this expression yields the New Keynesian Wage Phillips Curve.

We proceed with the first-order conditions of intermediate goods producers. The cost-minimization problem of each intermediate goods producer yields the following first-order condition for the demand for capital and labor:

$$r^K_t u^K_t = \alpha mc_{i,t} \frac{Y_{i,t}}{K_{i,t-1}}, \tag{F.7}$$

$$w_t = (1-\alpha) mc_{i,t} \frac{Y_{i,t}}{N_{i,t}}, \tag{F.8}$$

while the first-order condition for technology utilization is still given by (9).

The marginal cost faced by intermediate goods producers can be derived by combining the first-order conditions for labor and capital inputs, (F.7) and (F.8), with the production function (23). Dropping all subscript i's, we obtain:

$$\begin{aligned} r^K_t u^K_t &= \alpha mc_t \frac{u_t A N_t^{1-\alpha} \left(u^K_t K_{t-1} \right)^{\alpha}}{K_{t-1}} \Leftrightarrow \\ r^K_t &= \alpha A mc_t u_t \left(u^K_t \right)^{\alpha-1} \left(\frac{N_t}{K_{t-1}} \right)^{1-\alpha} \Leftrightarrow \\ \frac{N_t}{K_{t-1}} &= \left(\frac{r^K_t}{\alpha A mc_t u_t \left(u^K_t \right)^{\alpha-1}} \right)^{\frac{1}{1-\alpha}}, \end{aligned}$$

and:

$$\begin{aligned} w_t &= (1-\alpha) mc_t \frac{u_t A N_t^{1-\alpha} \left(u^K_t K_{t-1} \right)^{\alpha}}{N_t} \Leftrightarrow \\ w_t &= (1-\alpha) A mc_t u_t \left(u^K_t \right)^{\alpha} \left(\frac{N_t}{K_{t-1}} \right)^{-\alpha} \Leftrightarrow \\ \frac{N_t}{K_{t-1}} &= \left(\frac{w_t}{(1-\alpha) A mc_t u_t \left(u^K_t \right)^{\alpha}} \right)^{-\frac{1}{\alpha}}. \end{aligned}$$

We can combine these two expressions:

$$\begin{aligned} \left(\frac{w_t}{(1-\alpha) A mc_t u_t \left(u^K_t \right)^{\alpha}} \right)^{-\frac{1}{\alpha}} &= \left(\frac{r^K_t}{\alpha A mc_t u_t \left(u^K_t \right)^{\alpha-1}} \right)^{\frac{1}{1-\alpha}} \Leftrightarrow \\ \frac{w_t}{(1-\alpha) A mc_t u_t \left(u^K_t \right)^{\alpha}} &= \left(u^K_t \right)^{-\alpha} \left(r^K_t \right)^{-\frac{\alpha}{1-\alpha}} (\alpha A)^{\frac{\alpha}{1-\alpha}} \left(mc_t \right)^{\frac{\alpha}{1-\alpha}} \left(u_t \right)^{\frac{\alpha}{1-\alpha}} \Leftrightarrow \\ w_t &= (1-\alpha) \alpha^{\frac{\alpha}{1-\alpha}} A^{\frac{1}{1-\alpha}} \left(r^K_t \right)^{-\frac{\alpha}{1-\alpha}} \left(mc_t \right)^{\frac{1}{1-\alpha}} \left(u_t \right)^{\frac{1}{1-\alpha}} \Leftrightarrow \\ mc_t &= \frac{w_t^{1-\alpha} \left(r^K_t \right)^{\alpha}}{(1-\alpha)^{1-\alpha} \alpha^{\alpha} A u_t}, \end{aligned} \tag{F.9}$$

which is the expression presented in the main text.

F.1. Steady state and log-linearization

Compared to the simple model described in Section 3, our extended model introduces six new equations in the variables I_t, K_t, Q_t, r^K_t, u^K_t, and π^W_t. These are Eqs. (21), (F.3), (F.4), (F.5), (F.6), and (F.7). The steady-state versions of these equations give rise to the following relationships:

$$I = \delta K,$$

$$
\begin{aligned}
Q &= 1, \\
r^K &= \frac{1}{\beta} + \delta - 1, \\
\chi_1^K &= r^K, \\
\frac{\varepsilon_W - 1}{\varepsilon_W} &= \frac{\psi N^{\varphi}}{\lambda w}, \\
\frac{K}{Y} &= \frac{\alpha mc}{r^K},
\end{aligned}
$$

where we have used that $u^K = 1$ and $\pi^W = 1$ in steady state. In addition, several of the previous steady-state expressions are modified. Having pinned down the capital–output ratio above, we can write the production level as:

$$Y = \left[uAN^{1-\alpha} \left(\frac{K}{Y} \right)^{\alpha} \right]^{\frac{1}{1-\alpha}},$$

from which we can then back out the steady-state level of capital and, in turn, investment. The ratio of consumption to output then follows from the goods market clearing condition, and reads:

$$\frac{C}{Y} = 1 - \frac{g}{Y} - \frac{\delta K}{Y}.$$

The steady-state level of λ is:

$$\lambda = \frac{(1-\beta\theta)}{(C(1-\theta))^{\sigma}}.$$

The condition for labor market equilibrium is modified, and we now obtain the following expression for ψ:

$$\psi = \frac{\frac{\varepsilon_W - 1}{\varepsilon_W} (1-\beta\theta)(1-\alpha) mc A K^{\alpha}}{(C(1-\theta))^{\sigma} N^{\alpha+\varphi}}.$$

The log-linearized versions of the new equations are:

$$\hat{K}_t = (1-\delta)\hat{K}_{t-1} + \delta \hat{I}_t, \tag{F.10}$$

$$\hat{Q}_t = (1+\beta)\kappa \hat{I}_t - \beta\kappa \mathrm{E}_t \hat{I}_{t+1} - \kappa \hat{I}_{t-1}, \tag{F.11}$$

$$\mathrm{E}_t \hat{\lambda}_{t+1} + \beta r^K \hat{r}^K_{t+1} + \beta(1-\delta)\mathrm{E}_t \hat{Q}_{t+1} = \hat{\lambda}_t + \hat{Q}_t, \tag{F.12}$$

$$\hat{r}^K_t = \frac{\chi_2^K}{\chi_1^K} \hat{u}^K_t, \tag{F.13}$$

$$\hat{\pi}^W_t = \beta \mathrm{E}_t \hat{\pi}^W_{t+1} + \frac{1-\varepsilon_W}{\gamma_W}(1-\alpha)\frac{\varepsilon - 1}{\varepsilon}\left(\hat{\lambda}_t + \hat{w}_t - \varphi \hat{N}_t\right), \tag{F.14}$$

$$\hat{r}^K_t + \hat{u}^K_t = \widehat{mc}_t + \hat{Y}_t - \hat{K}_{t-1}. \tag{F.15}$$

We now have the following log-linearized first-order conditions for the household:

$$\hat{\lambda}_t = \mathrm{E}_t \left(\hat{\lambda}_{t+1} + \hat{R}_t - \hat{\pi}_{t+1} \right), \tag{F.16}$$

$$\sigma\beta\theta \mathrm{E}_t \hat{C}_{t+1} - \sigma\left(1+\beta\theta^2\right)\hat{C}_t + \sigma\theta\hat{C}_{t-1} = (1-\theta)(1-\beta\theta)\hat{\lambda}_t, \tag{F.17}$$

while the log-linear versions of the production function and the market-clearing condition become:

$$\hat{Y}_t = \hat{u}_t + (1-\alpha)\hat{N}_t + \alpha\left(\hat{u}^K_t + \hat{K}_{t-1}\right), \tag{F.18}$$

$$\hat{Y}_t = mc\hat{u}_t + \alpha mc \hat{u}^K_t + \frac{C}{Y}\hat{C}_t + \frac{I}{Y}\hat{I}_t + \frac{g}{Y}\hat{g}_t. \tag{F.19}$$

The monetary policy rule is now:

$$\hat{R}_t = \rho_r \hat{R}_{t-1} + \left(1-\rho_r\right)\left(\phi_\pi \hat{\pi}_t + \phi_y \hat{Y}_t\right). \tag{F.20}$$

Finally, wage inflation evolves according to:

$$\hat{\pi}^W_t = \hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_t. \tag{F.21}$$

Eqs. (D.5) to (D.8) are unchanged from the simple model. Our extended model thus consists of 16 variables in 16 equations. The variables are: $\hat{Y}_t, \hat{C}_t, \hat{g}_t, \hat{I}_t, \hat{K}_t, \hat{\pi}_t, \hat{\pi}^W_t, \hat{Q}_t, \widehat{mc}_t, \hat{\lambda}_t, \hat{u}_t, \hat{u}^K_t, \hat{w}_t, \hat{r}^K_t, \hat{N}_t, \hat{R}_t$, and the equations are (D.5)–(D.8) and (F.10)–(F.21).

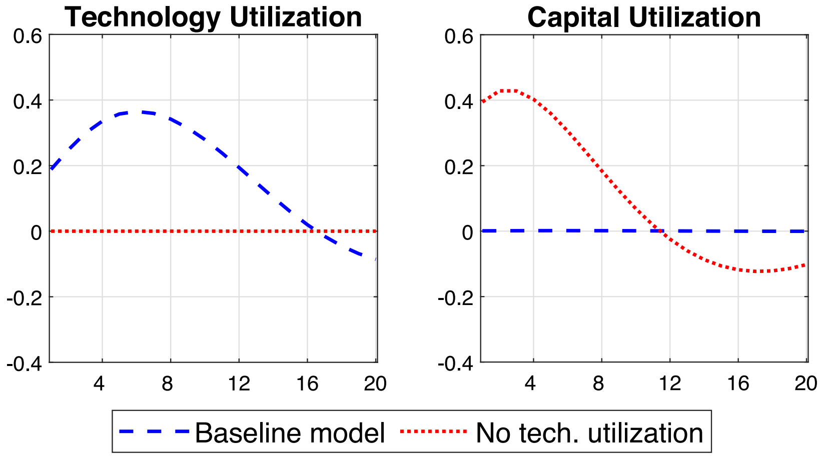

Fig. F.1. Impulse responses of technology and capital utilization rates in the estimated baseline DSGE model (dashed blue lines) and in the estimated DSGE model without variable technology utilization (dashed red lines) to a government spending shock of 1 percent. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

F.2. The response of technology and capital utilization

Fig. F.1 above reports the impulse-responses of the rates of technology and capital utilization to a government spending shock in our estimated baseline DSGE model and the alternative model. In the baseline model, the rate of technology utilization increases by around 0.4 percent at the peak, which amounts to roughly half of the increase in output. In contrast, the utilization rate of capital is practically constant due to high adjustment costs. In our alternative model without variable technology utilization, the rate of capital utilization increases by around 0.4 percent, which matches the increase in output in that model, whereas the rate of technology utilization is constant by construction.

Appendix G. Model dynamics at the zero lower bound

In this appendix, we study the properties of the model when the Zero Lower Bound (ZLB) on the nominal interest rate is binding.

G.1. The simple model at the ZLB

We first present the solution to a version of the simple model studied in Section 3 where the monetary policy rule has been replaced by a fixed nominal interest rate. To illustrate clearly the intuition, we find it useful to solve the model by simply replacing the Taylor rule with the following log-linear equation stating that the nominal interest rate remains constant:

$$\hat{R}_t = 0. \tag{G.1}$$

This is essentially an interest rate peg, as considered also in Section 2 of Bilbiie (2021) to offer clear analytical insights. Note that our approach does not take into account that the economy will eventually return to its steady state outside the ZLB.

Under an interest rate peg, the EE curve (D.10) is now replaced by the following expression:

$$-\hat{C}_t = \mathrm{E}_t\left(-\hat{C}_{t+1} - \hat{\pi}_{t+1}\right).$$

The NKPC-expression (D.13) is unaffected. We can then solve the model using the same steps as in Appendix D.3, except that in this case, we choose to solve the model without the assumption of zero shock persistence (i.e., we let $\rho_G \geq 0$). In this case, it can be shown that the solutions for consumption and inflation are:

$$\hat{C}_t = \frac{\rho_G}{1-\rho_G}\Theta\hat{g}_t, \tag{G.2}$$

$$\hat{\pi}_t = \Theta\hat{g}_t, \tag{G.3}$$

where

$$\Theta \equiv \frac{\frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(\frac{\chi_2}{\chi_1}-1\right)}{\left(1-\beta\rho_G\right)\left(\frac{\chi_2}{\chi_1}+3-2mc\right)-\frac{\varepsilon-1}{\gamma}\frac{\rho_G}{1-\rho_G}\left[\frac{\chi_2}{\chi_1}+1+\left(\frac{\chi_2}{\chi_1}-1\right)\frac{C}{Y}-mc\right]}.$$

Since the persistence parameter $\rho_G \in [0, 1)$, it is clear that the responses of consumption and inflation always have the same sign.[40] The sign of these responses, however, cannot immediately be determined. The sign will depend, all else equal, on the curvature of the adjustment cost function (χ_2)—or, in other words, the strength of the technology utilization mechanism—and the persistence of government spending shocks (ρ_G).

Before offering some numerical evidence on the conditions for obtaining positive or negative responses of $\hat{C}_t$ and $\hat{\pi}_t$, it is instructive to study the limits of the persistence parameter ρ_G, which satisfies $0 \leq \rho_G < 1$. Consider first the case of non-persistent shocks; $\rho_G = 0$. In this case, the solution for inflation simplifies to

$$\hat{\pi}_t = \frac{\frac{\varepsilon-1}{\gamma}\frac{g}{Y}\left(\frac{\chi_2}{\chi_1} - 1\right)}{\frac{\chi_2}{\chi_1} + 3 - 2mc}\hat{g}_t.$$

It is easy to show that this entails a *negative* response of inflation if and only if

$$\chi_2 < \chi_1.$$

Note that this is the exact same condition that ensures a decline in inflation away from the ZLB, as shown in Proposition 2 (which was also derived assuming $\rho_G = 0$): When the curvature of the utilization cost function is not *too large*, the presence of variable technology utilization leads to a drop in the inflation rate on impact.[41] Consider next the limiting case when $\rho_G \to 1$. In this case, it is possible to show that (G.3) entails a *positive* response of inflation (and consumption) when the parameter χ_2 belongs to the following interval:

$$\chi_1 > \chi_2 > \chi_1 \frac{mc - \frac{g}{Y}}{2 - \frac{g}{Y}}. \tag{G.4}$$

Notably, this interval coincides with the one required for the model to satisfy Propositions 1 and 2 in the main text simultaneously. When this condition is satisfied, and shocks are very persistent, an increase in inflation obtains.

To obtain a more complete picture, we now assign numerical values to all relevant parameters except χ_2 and ρ_G, so as to consider how the sign of the responses of $\hat{C}_t$ and $\hat{\pi}_t$ vary with these. All parameter values are chosen as in Appendix E.1. To repeat, we set $\varepsilon = 6$ (implying $mc = 0.833$), $\gamma = 29.41$ (implying that prices are reset on average every three quarters), $\frac{g}{Y} = 0.25$ (implying $\frac{C}{Y} = 0.75$), and $\beta = 0.99$. We also still have that $z'(1) = \chi_1 = mcAN$, implying that $\chi_1 = 0.21$ with our maintained assumptions of $A = 1$ and $N = 0.25$. Given these parameters, as also stated in Appendix E, the range of values of χ_2 given by (G.4) implies that $z''(\cdot) = \chi_2 \in [0.07; 0.21]$.

We report in Fig. G.1 the combinations of χ_2 and ρ_G for which the model returns a positive (white areas) or a negative (black areas) response of inflation (and thus, of consumption) at the ZLB.[42] The figure offers several important insights. In line with the arguments above, values of χ_2 belonging to the interval $[0.07; 0.21]$ entail a *negative* response of inflation (and consumption) at the ZLB, *unless* the government spending shock is sufficiently persistent. For values of $\chi_2 > 0.21$, the message is the opposite: Here, we observe a *positive* response of inflation, *unless* the shock is sufficiently persistent. Note that the latter statement is true as well for the textbook version of the New Keynesian model without variable technology utilization, which we obtain by letting $\chi_2 \to \infty$. In this case, we obtain a threshold value of $\rho_G = 0.59$, so that inflation responds positively when the persistence of the shock is lower than this number, and vice versa. We therefore observe that the presence of variable technology utilization—for the range of intermediate values of χ_2 indicated above—flips the predictions of the standard New Keynesian model at the ZLB upside down: For the values of χ_2 that were shown in Section 4 to produce a decline in inflation and an increase in consumption in response to a government spending shock in normal times, our model implies that a government spending shock at the ZLB leads to a *decline* in inflation (and consumption), unless the shock itself is very persistent; and thus that to obtain an *increase* in inflation (and consumption), the government spending shock needs to be sufficiently persistent. These findings are in direct contrast to the predictions of the textbook New Keynesian model. Finally, we repeat the same exercise in Fig. G.2 for a version of the model in which prices are very rigid (we set $\gamma = 142.86$, corresponding to prices being reset every six quarters on average). We see that increased price rigidity shifts the threshold value of ρ_G up. For high values of χ_2, we therefore find that it is less likely to observe a decline in inflation and consumption when prices are relatively sticky, as shown by Bilbiie (2021) for the New Keynesian model. In contrast, for the values of χ_2 studied in Section 4, more rigid prices reduce the probability of observing an increase in inflation and consumption.

G.2. The government spending multiplier at the ZLB

Fig. G.3 reports the impulse responses of some key variables to a government spending shock at the ZLB in the estimated versions of our New Keynesian model with and without variable technology utilization from Section 5. As the bottom-right panel shows, the

[40] The only exception is the limiting case of $\rho_G = 0$; see the next footnote.

[41] It can also be shown that in this case, the solution for consumption collapses to $\hat{C}_t = 0$. This reflects that although the government spending shock leads to a decline in inflation, the absence of any persistence means that *expected* inflation is unaffected, thus leaving also the real interest rate unchanged. In this special case, there is neither crowding-in nor crowding-out of private consumption.

[42] Note that the support for χ_2 considered in Figs. G.1 and G.2 is given by $\chi_2 \in [0.07; 2]$. The lower bound is given by the minimum value of χ_2 required to obtain a determinate equilibrium of the model away from the ZLB (see Proposition 1). The upper bound is simply chosen because the figure provides little additional insights beyond that value.

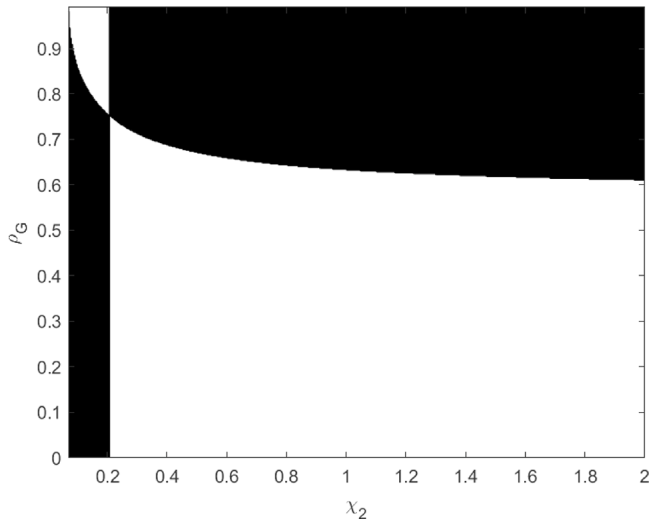

Fig. G.1. Sign of the impact responses of inflation and consumption to a government spending shock at the Zero Lower Bound for different values of the persistence of the shock (ρ_G) and the cost of changing the rate of technology utilization (χ_2). Black areas: Inflation and consumption decline. White areas: Inflation and consumption increase.

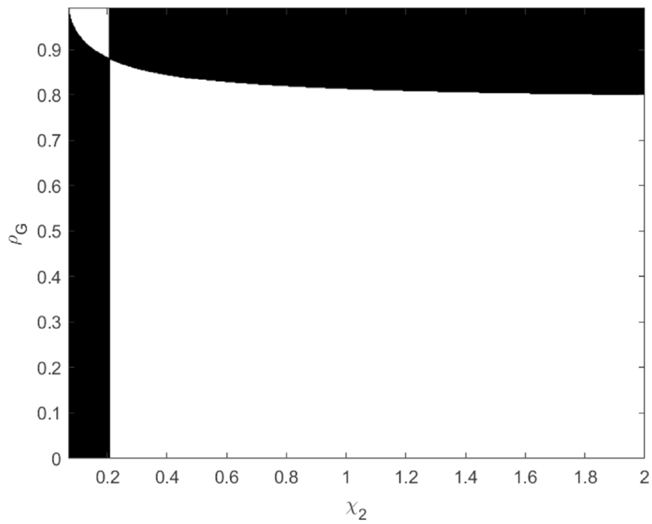

Fig. G.2. Sign of the impact responses of inflation and consumption to a government spending shock at the Zero Lower Bound for different values of the persistence of the shock (ρ_G) and the cost of changing the rate of technology utilization (χ_2) when prices are assumed very sticky. Black areas: Inflation and consumption decline. White areas: Inflation and consumption increase.

response of the (ex ante) real interest rate (given by $\hat{R}_t - E_t\hat{\pi}_{t+1}$) differs markedly between the two models. In our baseline model, we observe a drop in actual and expected inflation, which—in the face of a fixed nominal interest rate—leads to an increase in the real rate. In contrast, inflation displays an increase in the alternative model without variable technology utilization, leading to a decline in the real interest rate. The dynamics of the real interest rate is crucial for the responses of consumption and investment in the two models. In our baseline model, we observe a drop in consumption and a modest and short-lived increase in investment, whereas the alternative model features a flat response of consumption and a much larger increase in investment. In turn, these responses explain why output responds less strongly in our baseline model than in the alternative model when the ZLB is binding.

Appendix H. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.euroecorev.2021.103982.

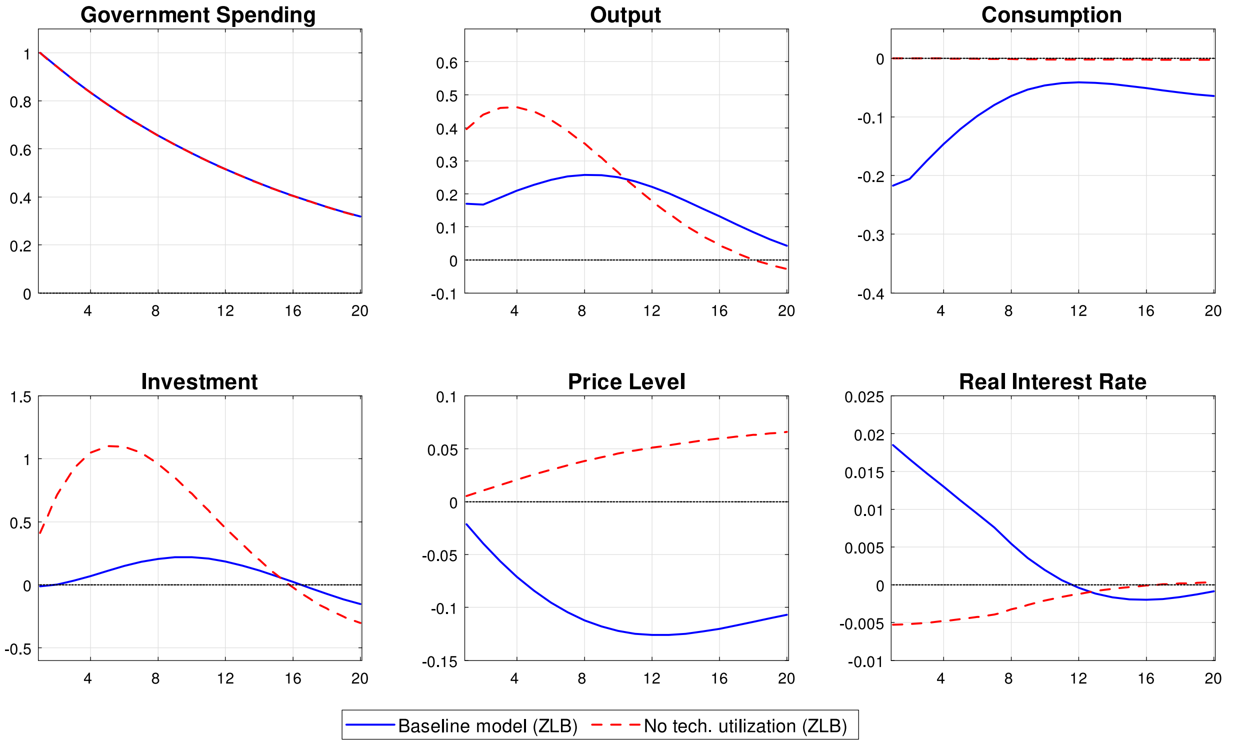

Fig. G.3. Impulse responses to a government spending shock of 1 percent at the Zero Lower Bound. Solid blue lines: estimated baseline DSGE model. Dashed red lines: estimated DSGE model without variable technology utilization.

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