Can public spending boost private consumption?

Stylianos Asimakopoulos
Department of Economics, University of Bath

Marco Lorusso
Department of Economics, Newcastle University Business School

Luca Pieroni
Department of Political Sciences, University of Perugia

Abstract. One of the most debated issues in modern macroeconomics relates to the behaviour of private consumption in response to an increase in government spending. Recent empirical studies have found a positive relationship between these two macroeconomic fundamentals. However, such a finding cannot be easily reconciled with simple real business cycle models. In this paper, we develop and estimate a new Keynesian model that is able to predict a rise in consumption in response to an increase in productive public spending. We show the two key elements that lead to a statistically significant positive reaction of private consumption, thereby creating consumption present-value multipliers, are: (i) a productive component in public spending and (ii) nominal rigidities. Our key results remain valid to various robustness checks that include a sub-sample analysis examining the pre-Great Recession period and a sensitivity analysis on the structural, fiscal and monetary policy parameters of the model.

Résumé. La dépense publique peut-elle stimuler la consommation des ménages? En macroéconomie moderne, l'une des questions les plus débattues concerne les comportements de consommation des ménages consécutifs à une augmentation des dépenses gouvernementales. De récentes études empiriques ont établi une relation positive entre ces deux fondamentaux macroéconomiques. Néanmoins, il reste difficile de concilier de

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Corresponding author: Stylianos Asimakopoulos, s.asimakopoulos@bath.ac.uk

We are grateful to Viktoriya Hnatkovska, a co-editor of the Canadian Journal of Economics, for her detailed comments. We would like to thank the anonymous referee for kindly agreeing to provide a review of our manuscript, careful reading and helpful comments. The preliminary results of this paper were presented at the seminar series of the Department of Political Science of the University of Perugia. We appreciate the feedback on this article from Achim Ahrens, Antonio Carvalho, Giorgio d'Agostino, Paul J. Dunne, Paolo Gelain and Francesco Ravazzolo. We are grateful for the financial support provided by the Department of Political Science of the University of Perugia. The standard disclaimer applies.

Canadian Journal of Economics / *Revue canadienne d'économique* 2021 54(3)
August 2021. Printed in Canada / *Août 2021. Imprimé au Canada*

ISSN: 0008-4085 / 21 / pp. 1275–1313 / © 2021 The Authors. *Canadian Journal of Economics/Revue canadienne d'économique* published by Wiley Periodicals LLC on behalf of Canadian Economics Association.

tels résultats avec les modèles de cycle réel. Dans cet article, nous développons et évaluons un nouveau modèle keynésien capable de prévoir une augmentation de la consommation consécutive à une hausse des dépenses publiques productives. Nous montrons que les deux facteurs clés conduisant à un effet positif statistiquement significatif sur la consommation des ménages, donc générateurs de multiplicateurs de consommation en valeur actualisée, sont: (i) une composante productive dans la dépense publique; et (ii) des rigidités nominales. Nos principaux résultats résistent à de nombreuses vérifications de robustesse, notamment une analyse de sous-échantillon examinant la période antérieure à la Grande Récession ainsi qu'une analyse de sensibilité relativement aux paramètres structurels, fiscaux et de politique monétaire du modèle.

JEL classification: C11, E27, E52, E62, H30

1. Introduction

The recent financial and sovereign debt crisis has pivoted the attention of policy-makers towards fiscal policy. In the United States, the introduction of the new fiscal package to stimulate demand, mainly through higher spending and lower taxes, according to the Congressional Budget Office's *2015 Long-Term Budget Outlook* (`www.cbo.gov/publication/50250`), led to a deficit of around \$5.6 trillion over the 2008–2012 period and a debt-to-output ratio of approximately 74% in 2015.[1] Moreover, the US presidency that commenced in January 2017 marked a significant change in terms of fiscal policy. President Trump proposed billions of dollars in spending cuts to most government agencies to pay for large increases in military and homeland security spending, resulting in a 1.2% cut in discretionary spending overall.[2] As a consequence, economists, the media and public opinion have renewed their interest in understanding the economic effects of the increase in government spending.

It is widely accepted that an expansionary fiscal policy through higher government spending will increase output. However, there is no consensus regarding the effects of changes to government spending on private consumption. A number of recent empirical studies have employed structural vector autoregressive (SVAR) models and show that higher government spending leads to higher private consumption.[3] On the contrary, standard real business cycle (RBC) models predict that an increase in government spending will cause a decline in private consumption due to the anticipation of higher debt financing via taxation, leading to a negative wealth effect.

1 This is the highest level of US debt in the post-WWII period.

2 For more details, please see the article "Who Wins and Loses in Trump's Proposed Budget" by Parlapiano and Aisch (2016).

3 See, for example, Blanchard and Perotti (2002), Fatás and Mihov (2003), Mountford and Uhlig (2009) and Perotti (2014).

In our study, we develop and estimate a new Keynesian dynamic stochastic general equilibrium (DSGE) model that is able to reconcile the empirical evidence provided by SVAR models within a DSGE framework. We examine the effect of productive and unproductive government spending changes on private consumption separately. Accordingly, we aim to identify which part of government spending could lead to an increase in private consumption and which model assumptions are necessary to obtain it.

We contribute to previous literature in several ways. Compared with Galí et al. (2007) and Bilbiie et al. (2008), we consider a wider range of nominal rigidities, a richer fiscal sector with distinct government spending components and distortionary taxation and find that a positive relationship between productive public spending and private consumption can be obtained in a model with homogenous agents. With respect to the works by Schmitt-Grohé and Uribe (2004) and Ravn et al. (2006), we show that the presence of productive government spending in combination with "superficial" habits and nominal rigidities is essential in order to generate the crowding-in effect on consumption.

We extend the studies by Baxter and King (1993), Ambler and Paquet (1996) and Linnemann and Schabert (2006) by considering a model that combines productive public spending with nominal rigidities, distortive taxes and several fiscal policy rules. We use a non-separable utility function between consumption and labour as in Linnemann (2006), Bilbiie (2009) and Bilbiie (2011), but, with respect to these studies, we also include a comprehensive set of nominal rigidities and a fiscal sector, embedding productive and unproductive government spending, as well as distortionary and non-distortionary taxation. Differently from Leeper et al. (2010b), we consider several fiscal policy rules in a new Keynesian framework with nominal rigidities and monetary policy.

Our model is estimated on the US economy using Bayesian techniques. This approach presents several advantages with respect to SVAR models, which have been strongly criticized for their use of timing restrictions through Cholesky decomposition,[4] and the narrative approach.[5] We use a dataset that allows us to distinguish between productive and unproductive public spending, following Kneller et al. (1999). In particular, overall government spending is split to assume that expenditures with a substantial (physical or human) capital component are "productive," whereas the "unproductive" spending category relates to government final wage and non-wage consumption expenditures.

We identify and estimate different fiscal rules for the two types of government spending. Our estimation procedure also allows us to obtain parameters for different debt financing sources (labour income taxes, capital income taxes

4 See, for example, Blanchard and Perotti (2002) and Fatás and Mihov (2003).

5 See, for example, Ramey (2011).

and lump-sum transfers). Thus, we extend the findings from previous literature that uses only lump-sum taxes as a financing mechanism for debt (see, for example, Coenen and Straub 2005).

We also contribute to the related literature by analyzing different fiscal policy experiments. In particular, we assess the output and consumption multipliers under different assumptions on: (i) financing methods, (ii) public spending share in the production function, (iii) speed of adjustment of different fiscal rules and (iv) different weights on output and inflation in the monetary rule.

Our main findings show that private consumption responds differently to productive and unproductive government spending shocks when the model exhibits nominal rigidities. In the case of a positive shock to productive public spending, we observe a stronger shift in labour demand compared with labour supply, together with high inflation, causing an increase in wage rates. This is sufficient to generate a crowding-in effect on private consumption. On the contrary, unproductive public spending exhibits high persistence, leading to prolonged high labour and capital taxes, together with low lump-sum transfers. As a result, there is a strong negative wealth effect on consumers, implying a significant crowding-out effect on private consumption. In addition, under the economy with nominal rigidities, a positive shock to productive spending has a positive effect on private consumption present-value multipliers not only in the short run but also in the long run. Under the "standard" neoclassical model, we observe similar results within the literature, irrespective of which component of public spending is being shocked. Finally, the output present-value multipliers are in line with the range of values reported in previous empirical studies.

We also show how different assumptions in modelling nominal rigidities affect the main transmission mechanisms of government spending shocks. In particular, our results indicate that price and wage indexations do not play a substantial role in terms of the response of private consumption to both productive and unproductive spending shocks. On the other hand, Calvo price and wage probabilities significantly affect crowding-in and crowding-out effects.

Our findings suggest that the method of financing matters in the long run. Different ways of financing have distinct effects on output and consumption multipliers depending on whether the economy is with or without nominal rigidities. We show that the positive reaction of private consumption under an increase in productive spending is present irrespective of the method of financing.

We also perform various robustness checks to test our key findings. First, we conduct a sub-sample analysis in order to verify whether our estimated results are influenced by the Great Recession period. Second, we use a sensitivity analysis with respect to the structural, fiscal and monetary policy parameters of our model. Our results show that the crowding in of private consumption following a positive shock to productive public spending remains valid.

In the next section, we briefly summarize the most important models in the related literature, assessing the effects of public spending on private consumption. Section 3 introduces our theoretical model. In section 4, we present the data used for the analysis and our Bayesian estimates. In section 5, we compare the impulse responses for productive and unproductive government spending shocks. Section 6 provides the results for consumption and output present-value multipliers. In section 7, we analyze the importance of nominal rigidities in the presence of government spending shocks. Section 8 presents several robustness checks. Section 9 concludes the paper.

2. Government spending shocks and consumption: A brief literature review

There is a vast economic literature concerning the impact of government spending shocks on private consumption. In this section, we describe the main results achieved from several models with distinct propagation mechanisms for government spending shocks that have been used in the quantitative analysis.

As we mentioned in the previous section, most of the empirical literature uses SVAR models with various identification schemes. A very large body of empirical literature includes structural restrictions on impulse response functions (Enders et al. 2011), relations among variables and error terms in the structural form (Corsetti et al. 2012) or external institutional information exploiting the quarterly nature of data and fiscal policy decision lags (Perotti 2005). Most of these papers find a positive correlation between private consumption and government spending, but they do not agree on the magnitude of the effect (see Blanchard and Perotti 2002 and Galí et al. 2007).

Smets and Wouters (2007) develop and estimate a new Keynesian model including only unproductive spending and assuming that any increase in debt used to finance the increased government spending is paid off by raising taxes in the future. Their empirical results show a small positive response of GDP to government spending shocks, whereas they find crowding out of both private investment and consumption.

Galí et al. (2007) and Bilbiie et al. (2008) show the importance of incorporating rule-of-thumb consumers together with price rigidities to generate a crowding-in effect on consumption, following a positive shock to government spending. The channel that gives rise to the crowding-in effect comes from the fact that non-Ricardian agents cannot react to higher future taxes, mitigating the negative impact on aggregate demand. Moreover, price rigidities minimize the negative impact on wage rates. Both of these effects lead to higher labour income, which boosts the consumption of households, inducing the crowding-in effect. Our model departs from these studies in different ways. Households are assumed to be homogenous and a wider range of nominal rigidities (such as sticky wages à la Calvo and price as well as wage indexation) are considered in combination with a rich fiscal sector that includes different public spending components (namely, productive and unproductive expenditures) and distortionary taxes (such as labour income tax and capital tax).

A different strand of literature analyzes the response of private consumption to government spending shocks in the presence of consumption habits. For example, Schmitt-Grohé and Uribe (2004) use a model with “superficial” habits and several nominal rigidities. Their results indicate that positive shocks to government spending induce the crowding-out effect on consumption. On the other hand, Ravn et al. (2006) implement a model with “deep” habits but without nominal rigidities and are able to obtain the positive reaction of private consumption to public spending shocks. Our model extends this literature by including the combination of “superficial” habits, nominal rigidities and productive government spending.

An alternative way to model the positive relationship between public spending and private consumption is offered by Baxter and King (1993) and Ambler and Paquet (1996). These studies present neoclassical models in which government spending enhances the productivity of firms and, therefore, contributes to aggregate production. Linnemann and Schabert (2006) extend these papers by introducing productive government spending in a new Keynesian framework. With respect to these studies, our model includes a larger set of nominal rigidities (such as sticky wages, price and wage indexation) and embeds distortionary taxation on labour income and capital as well as several fiscal policy rules.

Previous literature has also examined how the choice of a specific utility function can affect the response of consumption to government spending shocks. Using a simple RBC model, Linnemann (2006) shows that, under a specific utility function that is not additively separable between consumption and leisure and with a sufficiently strong complementarity of employment and consumption, it is possible to find a crowding-in effect on private consumption from an increase in government spending. Bilbiie (2009) extends this result using fully general non-separable preferences in a frictionless business cycle model. In particular, this author finds that an increase in private consumption in response to government spending shocks can be obtained only if the consumption good is inferior. Relying upon these works, Bilbiie (2011) uses a new Keynesian model with sticky prices and fully general non-separable preferences to generate the crowding-in effect on private consumption. In line with these papers, our model presents a utility function that is not separable between consumption and labour. With respect to this literature, our model includes a more comprehensive set of nominal rigidities (i.e., sticky wages, price and wage indexation) and a detailed fiscal sector with productive and unproductive government spending as well as distortionary and non-distortionary taxation.

Other studies have focused on the degree of complementarity between private and government consumption. For example, Coenen et al. (2012) introduce a utility function in which these two variables are non-separable and find a strong degree of complementarity between them. Such complementarity induces a positive response of private consumption to an exogenous increase in government consumption. Our model deviates from this line of reasoning by focusing on the effects of productive public spending, and its combination with nominal rigidities, on private consumption.

Leeper et al. (2010b) emphasize the importance of several fiscal rules in the US economy. They use a neoclassical growth framework with real frictions, and they include productive government spending in their model in order to assess the effects of various delays on the implementation of pre-announced public spending. These authors show the importance of debt financing and its implications on the economy, suggesting that lump-sum taxes/transfers do not have a significant effect on private consumption. In contrast, our analysis relies on a new Keynesian framework that includes nominal rigidities. As mentioned above, our results show that the presence of such rigidities is one of the key elements that induces a positive reaction of private consumption to productive government spending shocks.

A vast empirical literature suggests that the assumptions made on how the increased government spending is financed matters for the response of private consumption and output. For example, Mountford and Uhlig (2009) use a vector autoregression analysis to assess different ways of financing the increases in government spending. Forni et al. (2009) develop a dynamic stochastic general equilibrium model that include rules for distortionary taxes. In line with this literature, our paper provides a detailed analysis of the different ways of financing public spending on the basis of the fiscal rules included in our model. However, we contribute to these studies by taking into account the effects on private consumption due to shocks in different types of government spending, namely productive and unproductive government expenditures.

Finally, in a recent work, Kormilitsina and Zubairy (2018) are not able to reproduce the crowding-in effect on private consumption following a positive public spending shock in any of their estimated models, which incorporate most of the features used in the literature mentioned above. This is due to the fact that they assume pre-determined government spending. Fève et al. (2013) have shown that this modelling assumption is a source of misspecification that leads to a downward bias of the response of private consumption to a government spending shock. Therefore, following Fève et al. (2013), in our analysis we assume that there is a contemporaneous response of government spending to output. In the next section, we present our DSGE model in more detail.

3. Theoretical model

We will now describe our DSGE model, which assumes that there are two different types of public expenditure, namely, productive and unproductive government spending. Our theoretical framework is in line with the paper of Smets and Wouters (2007) and, in addition, it includes distortive taxes to capital and labour incomes together with several fiscal policy rules. Moreover, we assume that our economy has both nominal and real rigidities and that the central bank sets its policy rule.[6] In what follows, we are going to focus on the parts of the model that deviate from the Smets and Wouters (2007) set-up, while all the remaining equations are reported in online appendix A.

3.1. Households

We assume that the representative household trades a riskless one period government bond and accumulates physical capital that it rents out to firms. Moreover, it receives wage income and dividend payments from the firms. Therefore, the representative household maximizes the following utility function with two arguments, consumption (C_t) and labour (L_t):

$$\max E_t \left\{ \sum_{t=0}^{\infty} \beta^t \left[\left(\begin{array}{c} \frac{1}{1-\sigma^c} (C_t - hC_{t-1})^{1-\sigma^c} \cdot \\ \exp\left(\frac{\sigma^c - 1}{1+\sigma^l} (L_t)^{1+\sigma^l} \right) \end{array} \right) \right] \right\}, \tag{1}$$

where β^t is the discount factor, σ^c denotes the coefficient of relative risk aversion and σ^l is the inverse of the elasticity of work with respect to the real wage. The parameter h measures the degree of external habit formation in consumption.

The representative household faces the following budget constraint:

$$\frac{B_t}{\varepsilon_t^b R_t} = B_{t-1} + (1-\tau_t^l) W_t L_t + (1-\tau_t^k) R_t^k K_{t-1} + D_t - P_t C_t - P_t I_t + T_t, \tag{2}$$

where P_t indicates the price level, while R_t is the gross nominal return of government bonds denoted by B_t. As in Smets and Wouters (2007), ε_t^b is the exogenous risk premium shock and follows an AR(1) process. W_t denotes the wage rate, while R_t^k is the rental rate and D_t are the firm's dividends. C_t and I_t represent the private consumption good and investment good, respectively. The fiscal authority absorbs part of the gross income of the representative household to finance its expenditure. Accordingly, in equation (2), τ_t^l denotes the labour income tax rate, while τ_t^k is the capital income tax rate. Moreover, T_t indicates the lump-sum transfers from the government.

In addition, the representative household supplies its labour services to a labour union. The union uses Calvo (1983) contracts to set the wages charged to the intermediate firms. Finally, we allow for a partial indexation of wages to past inflation rates.

6 As in Smets and Wouters (2007), the central bank is assumed to follow a Taylor-type interest-rate rule (Taylor 1993).

3.2. Firms

We assume a continuum of monopolistically competitive firms indexed by $j \in [0, 1]$ producing differentiated varieties of intermediate production goods, and a single firm producing the final good combining the variety of intermediate production goods under perfect competition.

Each intermediate good firm j produces its differentiated output using a Cobb–Douglas technology with three input factors, i.e., private capital (K_t), labour (L_t) and productive government capital (K_t^{gp}):

$$\begin{aligned} Y_t(j) &= \varepsilon_t^a (K_t(j))^{\alpha_1} (L_t(j))^{\alpha_2} (K_t^{gp}(j))^{\alpha_3} \\ \text{where} \quad & \alpha_1 + \alpha_2 = 1 \\ \text{and} \quad & 0 < \alpha_3 < 1, \end{aligned} \tag{3}$$

where α_1 and α_2 indicate the private capital and labour share in production, respectively. With respect to the production function used by Smets and Wouters (2007), equation (3) displays an additional parameter associated with the productive government capital, that is α_3. This parameter denotes the public capital share in production.[7] Moreover, in equation (3), ε_t^a indicates the exogenous shock to total factor productivity following a first order autoregressive process. Firms set their prices according to current and expected marginal costs, but also according to the past inflation rate. The expression for the marginal cost is different from that of Smets and Wouters (2007) because, in our case, marginal cost does not depend on wages and the capital rental rate alone but depends also on the price of the productive government capital (see online appendix A).

In line with Baxter and King (1993) and Leeper et al. (2010b), we assume that the evolution equation for productive government capital is given by

$$K_{t+1}^{gp}(j) = (1 - \delta^g) K_t^{gp}(j) + G_t^p, \tag{4}$$

where δ^g is the parameter indicating the depreciation rate of the productive government capital. In equation (4), G_t^p indicates the productive government investment.[8]

7 In line with Baxter and King (1993), Glomm and Ravikumar (1997) and Leeper et al. (2010b), we model the production function in order to exhibit increasing returns to scale with respect to public capital.

8 In our model, we have also added the time-to-build feature in the spirit of Leeper et al. (2010b). In particular, we have assessed the impact of the time-to-build assumption on productive government capital by considering three distinct scenarios for implementation delays in productive government spending: six-month, nine-month and one-year time delays. Our findings show that, even with some periods of delay, private consumption increases once the productive government capital is in place. Therefore, the time delay assumption does not affect the robustness of our key result, namely that public government consumption crowds in private consumption (see online appendix H for more details).

We also assume that, in the intermediate production good sector, there is a sluggish price adjustment due to staggered price contracts à la Calvo. Finally, for firms whose prices cannot be adjusted in a given period, we allow for partial indexation to the past inflation rate.

3.3. Fiscal sector

Government budget constraint assumes that the finance of public spending takes place through issuing bonds or adjusting taxes and transfers. We separate government expenditure into productive (G_t^p) and unproductive (G_t^u) and, consequently, display a composite budget constraint as

$$G_t^u + G_t^p + B_{t-1} - T_t = \tau_t^r + \frac{B_t}{R_t}. \tag{5}$$

Moreover, total government distortionary tax revenues are given by

$$\tau_t^r = \tau_t^l W_t L_t + \tau_t^k R_t^k K_{t-1}. \tag{6}$$

We use fiscal policy rules that are in line with Leeper et al. (2010a):[9]

$$\hat{\tau}_t^l = \phi^{yl} \hat{y}_t + \gamma^{bl} \hat{b}_{t-1} + \hat{\varepsilon}_t^l, \tag{7}$$

$$\text{where } \hat{\varepsilon}_t^l = \rho^l \hat{\varepsilon}_{t-1}^l + \eta_t^l; \tag{8}$$

$$\hat{\tau}_t^k = \phi^{yk} \hat{y}_t + \gamma^{bk} \hat{b}_{t-1} + \hat{\varepsilon}_t^k, \tag{9}$$

$$\text{where } \hat{\varepsilon}_t^k = \rho^k \hat{\varepsilon}_{t-1}^k + \eta_t^k; \tag{10}$$

$$\hat{t}_t = -\phi^{yt} \hat{y}_t - \gamma^{bt} \hat{b}_{t-1} + \hat{\varepsilon}_t^t, \tag{11}$$

$$\text{where } \hat{\varepsilon}_t^t = \rho^t \hat{\varepsilon}_{t-1}^t + \eta_t^t; \tag{12}$$

$$\hat{g}_t^p = \phi^{yg^p} \hat{y}_t - \gamma^{bg^p} \hat{b}_{t-1} + \hat{\varepsilon}_t^{g^p}, \tag{13}$$

$$\text{where } \hat{\varepsilon}_t^{g^P} = \rho^{g^p} \hat{\varepsilon}_{t-1}^{g^p} + \eta_t^{g^p}; \tag{14}$$

$$\hat{g}_t^u = -\phi^{yg^u} \hat{y}_t - \gamma^{bg^u} \hat{b}_{t-1} + \hat{\varepsilon}_t^{g^u}, \tag{15}$$

$$\text{where } \hat{\varepsilon}_t^{g^u} = \rho^{g^u} \hat{\varepsilon}_{t-1}^{g^u} + \eta_t^{g^u}; \tag{16}$$

where $\hat{\varepsilon}_t^l$, $\hat{\varepsilon}_t^k$, $\hat{\varepsilon}_t^t$, $\hat{\varepsilon}_t^{g^p}$ and $\hat{\varepsilon}_t^{g^u}$ are assumed to follow distinct AR(1) processes and each of the η's is distributed i.i.d. N (0,1). All our fiscal policy rules have two characteristics. First, we assume that the fiscal variables respond to contemporaneous variations of output ($\phi^{yl} \geq 0$, $\phi^{yk} \geq 0$, $\phi^{yt} \geq 0$, $\phi^{yg^p} \geq 0$ and $\phi^{yg^u} \geq 0$). Second, our rules allow for dynamic responses to changes in

9 In equations (7) to (16), the small hatted letters denote that the variables are expressed in terms of log deviations around the deterministic steady state.

government debt ($\gamma^{bl} \geq 0$, $\gamma^{bk} \geq 0$, $\gamma^{bt} \geq 0$, $\gamma^{bg^p} \geq 0$ and $\gamma^{bg^u} \geq 0$). Moreover, in order to include the persistence in taxes, transfers and expenditures, we allow for the shocks to be serially correlated ($\rho^l \in [0,1]$, $\rho^k \in [0,1]$, $\rho^t \in [0,1]$, $\rho^{g^p} \in [0,1]$ and $\rho^{g^u} \in [0,1]$). In order to capture unexpected changes in distortionary taxes, lump-sum transfers and spending, we assume that fiscal rules (7), (9), (11), (13) and (15) include exogenous processes ($\hat{\varepsilon}_t^l$, $\hat{\varepsilon}_t^k$, $\hat{\varepsilon}_t^t$, $\hat{\varepsilon}_t^{g^p}$ and $\hat{\varepsilon}_t^{g^u}$, respectively).

In terms of the relationships of productive and unproductive government expenditures with output, our assumptions on fiscal rules (13) and (15) are motivated by previous economic literature.[10] Focusing on productive spending—equation (13)—Ambler et al. (2017) have shown that public investment has a positive response to an increase in aggregate productivity.[11] This finding implies that it is optimal for the government to increase productive government spending in the presence of a positive technology shock. Regarding unproductive spending—equation (15)—Leeper et al. (2010a) have used and estimated a government consumption spending rule in which government spending responds negatively to increases in aggregate output.[12]

3.4. Monetary policy

In line with Smets and Wouters (2007), the central bank is assumed to set the nominal interest rate according to the following Taylor rule (Taylor 1993):

$$\frac{R_t}{(R)^{SS}} = \left(\frac{R_{t-1}}{(R)^{SS}}\right)^{\rho} \left[\left(\frac{\pi_t}{(\pi)^{SS}}\right)^{r^{\pi}} \left(\frac{Y_t}{Y_t^p}\right)^{r^y}\right]^{(1-\rho)} \left(\frac{Y_t/Y_{t-1}}{Y_t^p/Y_{t-1}^p}\right)^{r^{\Delta y}} \varepsilon_t^r, \tag{17}$$

where $(R)^{SS}$ and $(\pi)^{SS}$ are the steady states of nominal interest rate and inflation, respectively. Moreover, ρ is the nominal interest smoothing parameter, r^{π} indicates the response of the nominal interest rate to lagged inflation from an inflation objective, r^y denotes the response of the nominal interest rate to the output gap,[13] and r^{Δ_y} is the response of the nominal interest rate to changes in the output gap. The monetary policy shock is

10 We have also conducted a structural vector autoregressive (SVAR) analysis to motivate our assumptions about government spending rules. Our empirical results (which are available upon request) support the choice of the signs that we have assumed in equations (13) and (15).

11 In their model, Ambler et al. (2017) consider government consumption spending, public investment and an exogenous component of government spending.

12 In their model, Leeper et al. (2010a) consider only government consumption spending.

13 As in Taylor (1993), we define the output gap as the difference between actual and potential output.

denoted by ε_t^r and follows an AR(1) process. Finally, Y_t^p indicates the natural output level.[14]

3.5. Market equilibrium

The final goods market is in equilibrium if the production of firms equals the demand by households for consumption and investment and government expenditures. Differently from standard new Keynesian models, in the aggregate resource constraint (18), we observe that total public spending is given by the sum of productive and unproductive government expenditures:

$$Y_t = C_t + I_t + G_t^u + G_t^p. \tag{18}$$

4. Estimated results

In this section, we describe the data and the estimation technique used in order to assess the theoretical model. Then, we discuss how we estimate the endogenous parameters and the exogenous processes related to the structural shocks. Finally, we present the main estimation results.

4.1. Data and estimation technique

We estimate our model using US quarterly data for the sample period 1963:Q2–2013:Q4.[15] The length of our sample relates to the data availability of our main source, namely the OECD Economic Outlook No. 90 (OECD 2011). In turn, the reason for choosing this source relates to the disaggregation of US government expenditure components, which is crucial for our analysis as we will explain below.

According to our theoretical set up, we consider 11 exogenous shocks so that 11 data series are used in our estimation. In particular, we use data on real gross domestic product, real private consumption, real private investment, real wage compensation, inflation rate, the federal funds effective rate, real labour tax revenues, real capital tax revenues, real productive government expenditure and real unproductive government spending and real government lump-sum transfers. In order to obtain the real variables, we deflate them using the US GDP deflator. Then, the real variables are converted into per capita terms by dividing for the working-age population.

14 As in Smets and Wouters (2007), the potential output is the level of output that prevails under the model with flexible prices and wages. The latter model is obtained by removing nominal rigidities as well as wage and price markup shocks from the model with rigid prices and wages.

15 The period 1960:Q2–1963:Q1 is used as pre-sample.

Following Leeper et al. (2010a) and Pfeifer (2014), we detrend the logarithm of each real variable separately,[16] while we demean the inflation rate and nominal interest rate.[17] All the details concerning data construction are shown in online appendix B.

In what follows, we prefer to focus on the variables that are "new" with respect to previous DSGE analysis on this topic (see, for example, Coenen et al. 2012 and Leeper et al. 2010a), namely real productive government spending, real unproductive government expenditure and real government transfers. As in Leeper et al. (2010a), we focus on federal government data for which comprehensive data on fiscal series exist. In particular, the OECD Economic Outlook No. 90 (OECD 2011) provides a detailed disaggregation of government expenditure components. As we explained above, our aim is to disentangle productive from unproductive government spending following the Kneller et al. (1999) approach. To this end, we assume that government productive expenditure is composed by government fixed capital formation, capital payments and government consumption of fixed capital. For the 1960–2013 period, the average share of this series on US GDP is about 6%. We further assume that unproductive government spending corresponds to the sum of government final wage consumption expenditure and government final nonwage consumption expenditure. On average the series consisted of around the 17% of US GDP during the 1960–2013 period. We assume that the series of government transfers is given by the sum of subsidies and social security benefits paid by the government.

As an estimation technique, we use the Bayesian approach. More specifically, the estimation of the model parameters by Bayesian maximum likelihood proceeds in two steps. First, we specify prior distributions for the parameters. Then, we combine this prior information with the likelihood of the model and characterize the posterior distribution. In order to approximate the posterior distribution of the parameters, we use Markov chain Monte

16 In particular, we use the Hodrick–Prescott filter with a smoothing parameter equal to 1,600.

17 Some studies (see, for example, Greenwood et al. 1997, Greenwood et al. 2000, Altig et al. 2011 and Schmitt-Grohé and Uribe 2012) have estimated DSGE models including one or two common stochastic trends. This strategy is feasible when the number of trends is limited to one or two, but it becomes non-trivial in the presence of a larger number of trends. In this regard, Leeper et al. (2010a) argued that, in models analyzing fiscal policy, the number of trends is often larger than two because several fiscal variables display their own trends. Moreover, some of these variables, such as transfers, show upward trends, and this requires specific modeling assumptions in order to guarantee fiscal sustainability. Indeed, online appendix C shows that the fiscal series included in our analysis clearly display different trends in the sample period considered. Accordingly, as an estimation strategy, we prefer to follow the treatment of observed variables used by Leeper et al. (2010a).

Carlo (MCMC) methods. Specifically, we use the Metropolis–Hastings algorithm to generate parameter observations on which to base inference.[18]

4.2. Fixed parameters and prior distributions

Before discussing the estimation results, we will first describe the choice of the prior distributions. Table 1 presents the values assigned to fixed parameters. These parameters can be viewed as very strict priors because they can be directly related to the steady-state values and are not identifiable from the data we use. For these values, we assume "standard" parameters extracted from the most recent DSGE literature. The discount factor (β) is calibrated to be 0.996, in line with the value assumed by Del Negro and Schorfheide (2008).

The depreciation rate of private capital (δ) is set at 0.025 per quarter, which implies an annual depreciation on capital of 0.10. We assume that the intertemporal elasticity of substitution ($\frac{1}{\sigma^c}$) corresponds to a coefficient of relative risk aversion equal to 5.[19]

We set up the elasticity of labour supply (σ^l) equal to 0.04. Although this value is in the lower range of estimates that have been provided by previous literature,[20] as a sensitivity analysis, we increased the value of the Frisch elasticity 5 and 50 times, and we show that our main findings remain robust to these changes.[21]

As in Smets and Wouters (2007), the steady-state markup in the labour market (ϕ^w) is equal to 1.5, and we assume that the steady-state markup in the goods market (ϕ^p) is equal to 1.5 as well. Moreover, as in Smets and Wouters (2007), the curvature parameters of the Kimball aggregators in the goods (ϑ^p) and labour market, (ϑ^w), are both set at 10.

Differently from Smets and Wouters (2007) and Del Negro and Schorfheide (2008), we have a set of fixed parameters related to the fiscal sector. In particular, the relative shares of productive (g^{py}) and unproductive (g^{uy}) government expenditures on GDP are computed as average ratios for the 1960–2013 period, and are equal to 0.06 and 0.17, respectively. The steady-state tax rates for capital, $(\tau^k)^{ss}$, and labour, $(\tau^l)^{ss}$, are obtained from average capital and labour income tax rates, respectively, and computed from our sample data. The share of transfers on GDP has been computed residually from the government's budget constraint using the steady states reported above and a steady

18 All our estimations are done with Dynare (`www.dynare.org`).

19 This value of the risk aversion is commonly used in the macroeconomic literature (see, for example, Jermann 1998).

20 As reported by Peterman (2016), original microeconometric estimates of the elasticity of labour supply are between 0 and 0.54 (see MaCurdy 1981 and Altonji 1986). In contrast, other studies calibrate the elasticity of labour supply in macroeconomic models in the range of 2 to 4 (Chetty et al. 2013).

21 The results of this robustness check are provided in section 8.2.

TABLE 1

Fixed parameters according to quarterly data

Parameter	Symbol	Value	Target/source
Discount factor	β	0.996	Del Negro and Schorfheide (2008)
Depreciation rate of private capital	δ	0.025	Annual capital depreciation: 0.10
Intertemporal elasticity of substitution	$\frac{1}{\sigma^c}$	0.2	Jermann (1998)
Elasticity of labour supply	σ^l	0.04	Altonji (1986)
Steady-state markup in goods market	ϕ^p	1.5	Smets and Wouters (2007)
Steady-state markup in labour market	ϕ^w	1.5	Smets and Wouters (2007)
Goods market aggregate curvature	ϑ^p	10	Smets and Wouters (2007)
Labour market aggregate curvature	ϑ^w	10	Smets and Wouters (2007)
Productive government expenditure/ GPD	g^{py}	0.06	From our data sample
Unproductive government expenditure/ GPD	g^{uy}	0.17	From our data sample
Government transfers/GDP	t	0.12	From our data sample
Steady-state capital tax rate	$(\tau^k)^{SS}$	0.28	From our data sample
Steady-state labour tax rate	$(\tau^l)^{SS}$	0.26	From our data sample
Depreciation rate of government capital	δ^g	0.005	Leeper et al. (2010b)

state of debt to output ratio of approximately 53%, which is the average annual debt to output ratio for the period under consideration. As in Baxter and King (1993) and Leeper et al. (2010a), we assume that the depreciation rate for the government capital expenditure (δ^g) corresponds to 0.005.[22]

Tables 2 and 3 report the remaining parameters of the model estimated with Bayesian techniques. Our prior mean for habit in consumption (h) is in line with the values used by Jermann (1998) and Constantinides (1990). Regarding the prior for the investment adjustment costs (S''), we set it in line with Ravn et al. (2012) and Schmitt-Grohé and Uribe (2012). The prior mean for the private capital share in the production function (α_1) is set following Leeper et al. (2010b) calibration. We also estimate the parameter indicating the public capital share in the production function (α_3) assuming a prior for α_3 equal to 0.15, which is within the range applied in the related literature (see Leeper et al. 2010b and references therein).[23]

22 In particular, Leeper et al. (2010b) have the exact same value for the depreciation rate of private capital as we assume in our model ($\delta = 0.025$). They also set the annual depreciation rate of public capital (δ^g) equal to 0.020, which corresponds to a quarterly value of 0.005. We make the same assumption in our study. In addition, as a robustness check, we have assumed the same values for both depreciation rates of private and public capital. In online appendix H, we show that our key results remain robust even using this assumption.

23 The related empirical literature on public spending has diverse views on the share of public spending in the production ranging from a significant value of 0.24 (Aschauer 1989), to insignificant (Kamps 2004) or even a negative value (Evans and Karras 1994).

TABLE 2
Priors and posteriors for the endogenous parameters

Parameter	Description	Priors			Posteriors		
		Distribution	Mean	St. dev.	Mean	Confidence intervals	
h	Consumption habit persistence	Beta	0.85	0.01	0.81	0.79	0.83
$S^{''}$	Investment adjustment cost	Gamma	7.00	1.50	15.21	12.49	17.87
α_1	Private capital share in production	Gamma	0.30	0.01	0.28	0.26	0.29
α_3	Public capital share in production	Inverse gamma	0.15	0.15	0.13	0.05	0.23
ξ^w	Calvo wages probability	Beta	0.30	0.01	0.32	0.31	0.34
ξ^p	Calvo prices probability	Beta	0.30	0.01	0.32	0.30	0.33
ι^w	Degree of wage indexation	Beta	0.10	0.05	0.16	0.04	0.26
ι^p	Degree of price indexation	Beta	0.10	0.05	0.18	0.06	0.29
ρ	Interest rate amoothing	Gamma	0.60	0.01	0.61	0.59	0.63
r^{π}	T.R. coefficient on inflation	Gamma	2.00	0.25	2.98	2.52	3.43
r^y	T.R. L.R. coefficient on Y	Gamma	1.00	0.10	0.77	0.65	0.89
r^{Δ_y}	T.R. S.R. coefficient on Y	Gamma	1.20	0.05	0.97	0.91	1.02
ϕ^{yl}	τ^l/Y Coefficient	Gamma	0.10	0.05	0.33	0.10	0.54
ϕ^{yk}	τ^k/Y Coefficient	Gamma	0.40	0.20	2.66	2.21	3.17
ϕ^{yt}	T/Y Coefficient	Gamma	0.10	0.05	0.15	0.04	0.26
γ^{bl}	τ^l/B Coefficient	Gamma	0.05	0.04	0.19	0.01	0.35
γ^{bk}	τ^k/B Coefficient	Gamma	0.30	0.15	0.41	0.10	0.71
γ^{bt}	T/B Coefficient	Gamma	0.50	0.20	0.42	0.04	0.77
ϕ^{yg^p}	G^p/Y Coefficient	Gamma	0.15	0.05	0.12	0.06	0.18
ϕ^{yg^u}	G^u/Y Coefficient	Gamma	0.15	0.05	0.27	0.13	0.40
γ^{bg^p}	G^p/B Coefficient	Gamma	0.40	0.20	0.52	0.18	0.84
γ^{bg^u}	G^u/B Coefficient	Gamma	0.40	0.20	0.30	0.06	0.53

NOTES: T.R. = Taylor rule. L.R. = long run. S.R. = short run.

Turning to nominal rigidities, we assume prior means for the parameters of Calvo wage (ξ^w), Calvo price (ξ^p), wage indexation (ι^w) and price indexation (ι^p) in line with Le et al. (2011).[24] Regarding the parameters of the monetary policy rule, the prior for the degree of interest rate smoothing (ρ) is similar to the one used by Del Negro and Schorfheide (2008). We assume that the priors for the long-run reaction coefficients of inflation (r^{π}) and output (r^y) are gamma distributed with means equal to 2 and 1, respectively, and standard deviations of 0.25 and 0.10, respectively. In addition, we set the prior of the short-run coefficient of output (r^{Δ_y}) as gamma distributed with mean equal to 1.20 and standard deviation of 0.05.

Focusing on the priors for the coefficients of the fiscal sector, we assume rather loose priors in order to cover a large range of parameter values. The

24 In their study, Le et al. (2011) estimate a model of the US economy for the post-war period, using indirect inference, the bootstrap and a vector autoregressive (VAR) representation of the data. They suggest that limited nominal rigidities fit better with actual data.

TABLE 3

Priors and posteriors for the shock processes parameters

Parameter	Priors			Posteriors		
	Distribution	Mean	St. dev.	Mean	Confidence intervals	
Risk premium persistence: ρ^b	Beta	0.70	0.20	0.06	0.01	0.10
Investment persistence: ρ^i	Beta	0.70	0.20	0.68	0.58	0.77
Wage markup persistence: ρ^w	Beta	0.70	0.20	0.14	0.06	0.22
Price markup persistence: ρ^p	Beta	0.70	0.20	0.61	0.37	0.82
Productivity persistence: ρ^a	Beta	0.70	0.20	0.96	0.92	0.99
Productive government exp. persistence: ρ^{g^p}	Beta	0.70	0.20	0.79	0.69	0.90
Unproductive government exp. persistence: ρ^{g^u}	Beta	0.70	0.20	0.99	0.98	0.99
Government transfers persistence: ρ^t	Beta	0.70	0.20	0.72	0.63	0.81
Capital tax persistence: ρ^k	Beta	0.70	0.20	0.79	0.72	0.86
Labour income tax persistence: ρ^l	Beta	0.70	0.20	0.73	0.66	0.80
Monetary policy persistence: ρ^r	Beta	0.70	0.20	0.63	0.55	0.71
Risk premium standard error: σ^b	Inverse gamma	1.00	Inf	0.28	0.26	0.31
Investment standard error: σ^i	Inverse gamma	1.00	Inf	0.49	0.41	0.58
Wage markup standard error: σ^w	Inverse gamma	1.00	Inf	0.77	0.68	0.85
Price markup standard error: σ^p	Inverse gamma	1.00	Inf	0.24	0.20	0.28
Productivity standard error: σ^a	Inverse gamma	1.00	Inf	0.31	0.19	0.43
Productive government exp. standard error: σ^{g^p}	Inverse gamma	1.00	Inf	1.48	1.03	1.92
Unproductive government exp. standard error: σ^{g^u}	Inverse gamma	1.00	Inf	3.27	2.97	3.57
Government tansfers standard error: σ^t	Inverse gamma	1.00	Inf	1.81	1.65	1.96
Capital tax standard error: σ^k	Inverse gamma	1.00	Inf	4.24	3.86	4.62
Labour inc. tax standard error: σ^l	Inverse gamma	1.00	Inf	2.42	2.21	2.63
Mon. policy standard error: σ^r	Inverse gamma	1.00	Inf	0.61	0.55	0.68

NOTES: exp. = expenditure. Inf = inflation.

priors for the parameters of lump-sum transfers (ϕ^{yt}) and labour tax rate (ϕ^{yl}) elasticities with respect to output are assumed to have gamma distributions with the same mean of 0.10 and the same standard deviation of 0.05. In addition, we assume that the prior for the parameter of the capital tax rate (ϕ^{yk}) elasticity with respect to output ranges between 0 and 1.5 approximately. Moreover, as in Leeper et al. (2010b), our assumed prior distributions for the responses of labour income tax (γ^{bl}), capital tax (γ^{bk}) and lump-sum transfers (γ^{bt}) to government debt cover a large range of possible estimated values. In particular, γ^{bl} will range, approximately, between 0 and 0.25, γ^{bk} between 0 and 0.75 and, finally, γ^{bt} between 0 and 1.

As a contribution with respect to previous studies, we distinguish between two different types of government spending. We assume two distinct parameters that measure the responses of productive and unproductive government expenditures to output, namely, ϕ^{yg^p} and ϕ^{yg^u}. As far as we know, our study is the first that attempts to estimate the value for these parameters. Our assumed prior distributions for ϕ^{yg^p} and ϕ^{yg^u} are fairly general and cover the range of values found by previous papers, which estimated the response of aggregate government spending to output (see, for example, Blanchard and Perotti 2002 and Yang 2005). Moreover, our model includes two different parameters that indicate the responses of productive and unproductive government expenditures to debt, i.e., γ^{bg^p} and γ^{bg^u}, respectively. We assume diffuse prior distributions for these parameters in order to cover a reasonable range of parameter values.[25]

Finally, we focus on the priors of the parameters related to all the exogenous processes in our model. As in Leeper et al. (2010b), we set the persistence parameters for all AR(1) exogenous processes to be as beta distributions with means of 0.70 and standard deviations of 0.20. We use inverse gamma distributions for the standard errors of all exogenous shocks with means equal to 1 and infinite degrees of freedom, which correspond to rather loose priors.

4.3. Parameter identification

In order to estimate the model, we used a sample of 1,000,000 draws (dropping the first 250,000 draws), obtaining an acceptance rate of around 33%. To test the stability of the sample, we used the Brooks and Gelman (1998) diagnostic test, which compares within and between moments of multiple chains.

We also performed several diagnostic tests for our estimates, including the Markov chain Monte Carlo (MCMC) univariate diagnostics and the multivariate convergence diagnostics.[26] In order to evaluate whether our estimated model fits with the US economy, we calculated the business cycle statistics implied by our model and compared them with those derived from the data. The results show that our estimated model is able to match the business cycle statistics of the key variables.[27]

As is well known, poorly identified parameters would result in distorted implications for the impulse response analysis and the estimation of the fiscal multipliers. Therefore, we assessed the prior and posterior distributions. As we show in online appendix D, for most of the parameters, the prior probability density functions are wide, and the posterior distributions are different from the priors. In addition, we conducted the test proposed by Iskrev (2010), which essentially checks the identification strength and sensitivity component

25 In this regard, our prior distributions cover the range of values found by Leeper et al. (2010b), who have estimated the response of aggregate government spending to the debt-to-output ratio.

26 These are shown in online appendix D.

27 In online appendix E, we report the business cycle statistics implied by our model and those obtained from actual data.

of the parameters on the basis of the Fischer information matrix and the moment information matrix, normalized by either the parameter at the prior mean or by the standard deviation at the prior mean.[28] The results of this test show that the derivative of the vector of the predicted autocovariogram of observables with respect to the vector of estimated parameters has full rank when we evaluate it at the posterior mean estimate. This implies that all parameters are identifiable in the neighborhood of our estimates.

4.4. Posterior estimates

Tables 2 and 3 show the posterior means for the model parameters together with a 90% confidence interval.[29] Our estimate of the external habit stock is about 80% of past consumption. The posterior mean estimate for $S^{''}$ is higher than its prior mean, suggesting an even slower response of investment to changes in the value of capital. Our estimate of α_1 is 0.28, which corresponds to a share of about two thirds of labour to output. The posterior mean of the parameter indicating the public capital share in the production function (α_3) corresponds to 0.15, which is within the range suggested in the related literature (see Aschauer 1989, Evans and Karras 1994, Kamps 2004 and Leeper et al. 2010b).

In terms of nominal rigidities, our posterior mean estimates suggest that both prices and wages are flexible and change roughly every four months on average. Comparing our estimated results with previous studies analyzing the US economy, we note that our estimated ξ^w is within the range of the values found by previous DSGE models, such as those of Rabanal and Rubio-Ramírez (2005) and Del Negro and Schorfheide (2008). Moreover, our estimate of ξ^p is in line with the values found by previous macroeconometric studies, such as those of Bils and Klenow (2004) and Bartosz and Smets (2008). Turning to the posterior estimates of wage and price indexations, our findings indicate low values for both these parameters. Our results are in line with several studies on the US economy. In particular, our estimated ι^w falls

28 We report the results of this test in online appendix F. Further graphs about collinearity and identification patterns are available upon request.

29 We have checked the robustness of our estimates by including the possibility of the zero lower bound (ZLB) on the interest rate in our model. Our empirical results indicate very similar values for the estimated parameters in both models with and without the ZLB. This finding may be explained by the fact that our data sample (1963:Q2–2013:Q4) is not greatly affected by the recent period of the zero lower bound on the interest rate, which lasted for just six years in our sample (it accounts for roughly 12% of the overall sample). In this regard, we acknowledge that our standard approach in terms of Bayesian estimates does not accommodate for different regimes or states within our DSGE model. Such limitation does not allow us to consider the possibility of endogenous (policy and non-policy) parameters changing in combination over time. We leave this topic for future research.

within the range of values found by previous DSGE models, such as those of Del Negro and Schorfheide (2008) and Galí et al. (2012). In terms of price indexation, our estimated ι^p is in line with the empirical value found by Khan and Tsoukalas (2012) in their DSGE model.

Focusing on our estimates of the monetary policy reaction function, the posterior mean of the reaction coefficient to inflation is estimated to be substantially high. The nominal interest rate appears to react less strongly to the output gap in the long run than in the short run, whereas the posterior of the degree of interest rate smoothing does not vary substantially from its prior mean.

In general, the estimated posteriors of the fiscal rule parameters are well identified. We observe that the capital tax response is much more procyclical than the labour tax response. Similarly, capital tax responds more strongly than labour tax to changes in government debt. This is in line with the optimal fiscal policy literature, which suggests that capital taxes should operate as a buffer mechanism for the government against uncertainty, whereas labour taxes should be held relatively smooth over the business cycle (Barro 1979, Chari et al. 1994 and Angelopoulos et al. 2015). In addition, we found that lump-sum transfers respond strongly to changes in the debt-to-output ratio, while they have a low response to output deviations. As a result, the estimated fiscal rules show a preference towards the use of non-distortionary taxation to stabilize debt, whereas capital tax is the most reactive fiscal policy instrument for output stabilization.

Focusing on the two different types of government expenditure, our estimated results show that the unproductive government spending has a stronger response to changes in output than productive expenditure. The productive government expenditure responds more strongly than unproductive government spending to debt variations. In this regard, our results contribute to previous economic literature by convincingly quantifying the economic effects of the alternative methods of financing public expenditure.[30]

Turning to the exogenous processes, the risk premium shock, the investment shock, the monetary policy shock, the price and wage markup shocks show a lower persistence than the one assumed in their prior distributions. Moreover, our results show that unproductive government spending is more persistent than the productive government expenditure. The persistence of the capital tax is higher than labour tax and transfers. Finally, our posterior

30 In this regard, Lorusso and Pieroni (2017) and Barro (1979) and Barro (1981) have stressed the importance of the economic effects of government spending and its alternative financing methods. In particular, Lorusso and Pieroni (2017) have focused on different public spending components, namely civilian and military expenditures.

estimates show that labour and capital income tax shocks are the most volatile among fiscal variables and are more volatile than the remaining shocks.[31]

5. Impulse response analysis

This section presents the impulse responses of the key variables in our economy following a 1% exogenous positive shock to productive and unproductive government spending separately.[32] For the impulse response analysis, we set the values of the estimated parameters equal to their mean estimates of the posterior distribution.[33] In figures 1 and 2, we include two lines: (i) the solid line representing the economy with nominal rigidities and (ii) the dashed line indicating the economy with flexible prices and wages (without nominal rigidities).[34]

5.1. Productive government expenditure

Figure 1 shows that, in both the economies with and without nominal rigidities, a positive shock to productive government spending induces an increase in output for all periods. Moreover, the rise in productive government expenditure induces an increase in aggregate demand and the labour marginal product rises. As a consequence, labour demand increases. At the same time, the higher government spending implies an increase in the tax burden (in present-value terms), thereby inducing a negative wealth effect on households who, therefore, raise their labour supply.

31 Our findings confirm actual data. In online appendix E, we show that the volatilities of the series of capital and labour tax rates are high and, in particular, the fact that these tax rates are more volatile than the series of government expenditures. In general, we note that our model is able to replicate the US business cycle statistics quite accurately.

32 As a robustness exercise, we have also estimated an SVAR model in the spirit of Lorusso and Pieroni (2017). Qualitatively, the results of the SVAR confirm the main transmission mechanisms predicted by our DSGE model. We present the findings of this SVAR analysis in online appendix I.

33 Qualitatively the results of the impulse response analysis are the same if we use the estimated standard deviation of the shocks instead of the simulated 1% standard deviation. We simply normalize the shock to the economy to be 1% to ease the comparison of the impulse responses between the two cases of productive and unproductive government spending. In online appendix G, we present the estimated impulse responses together with the confidence intervals.

34 As in Smets and Wouters (2007), the model with flexible prices and wages is obtained by removing nominal rigidities, as well as price and wage markup shocks from the model with rigid prices and wages. In online appendix A, we report the equations for the flexible-price-and-wage version of the model.

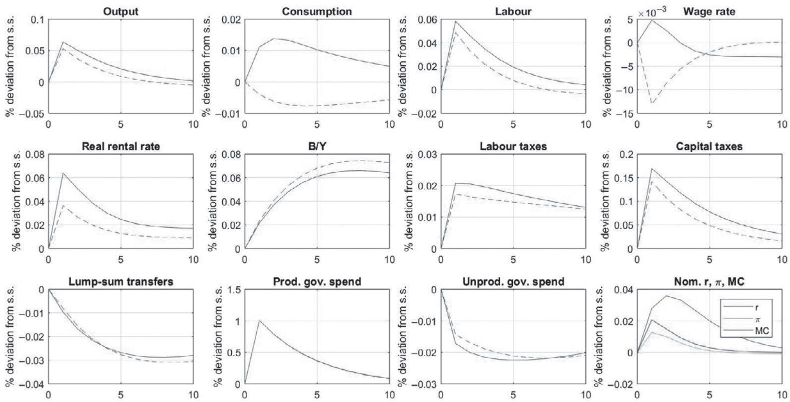

FIGURE 1 Impulse responses to a 1% increase in productive public spending
NOTES: Solid lines indicate an economy with nominal rigidities. Dashed lines are for the economy without nominal rigidities. All variables are in percentage deviations from their steady state. X-axis is in quarters. B = debt. MC = marginal cost. s.s. = steady state. Y = output.

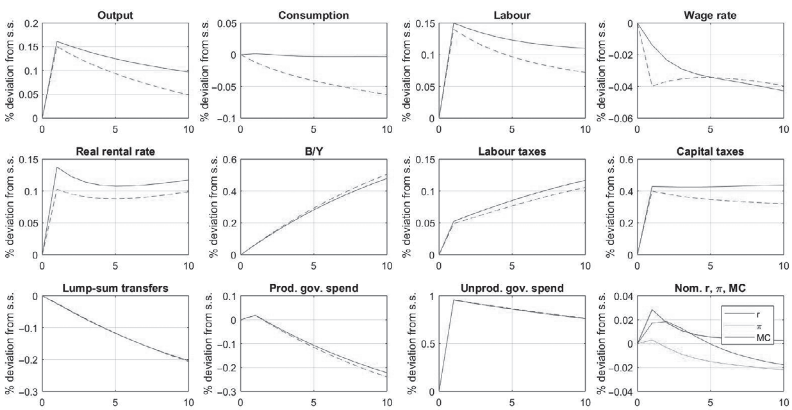

FIGURE 2 Impulse responses to a 1% increase unproductive public spending
NOTES: Solid lines indicate an economy with nominal rigidities. Dashed lines are for the economy without nominal rigidities. All variables are in percentage deviations from their steady state. X-axis is in quarters. B = debt. MC = marginal cost. s.s. = steady state. Y = output.

In figure 1, we observe that the response of private consumption differs between the economy with nominal rigidities and the economy with flexible prices and wages. This result depends on the reaction of the wage rate. In the economy with nominal rigidities, the wage rate increases, whereas the opposite occurs in the economy without nominal rigidities. In particular, the response of the real wage depends on the interaction between labour demand and supply. In the presence of nominal rigidities, firms cannot adjust their prices, but they have to satisfy the higher aggregate demand by increasing their labour demand. In this case, the shift in labour demand dominates the shift in labour supply and the real wage increases. In turn, this result implies a positive response of private consumption. On the other hand, in the economy with flexible prices and wages, we observe the crowding-out effect on consumption.

In the economy with nominal rigidities, the increase in productive government spending induces an increase in the firms' marginal cost and inflation. In particular, we observe that firms' prices over the marginal cost decrease, leading to an additional upward pressure on prices. As can be seen from the impulse responses, the ratio of the price over the marginal cost decreases following the productive spending shock because marginal cost increases more than inflation. In response to the increase in inflation, the monetary authority raises its policy rate.

In response to the increase in public spending, debt rises as it is the residual fiscal instrument for the government and given that the increase of the remaining fiscal instruments (i.e., labour and capital taxes) and the decline in transfers (that follow a predetermined estimated rule) only partially fund the exogenous increase in public spending. As a result, the rise in public spending does not increase debt on a one-to-one basis. Finally, the unproductive government spending drops because $\hat{g}_t^u$ depends exclusively on counter-cyclical reactions to output and debt.

Our findings are in line with the findings of Bilbiie et al. (2008), which show that strong shifts in labour demand may imply a positive reaction of private consumption under an exogenous increase in productive public spending. On the contrary, under the economy with flexible prices and wages, private consumption decreases. This is the standard neoclassical result where the negative wealth effect on households lowers private consumption due to the expected future taxation that will fund the increase in public spending (see, for example, Baxter and King 1993).

5.2. Unproductive government expenditure

As we can see from figure 2, following the unproductive government spending shock, the reactions of output and debt are again positive. The initial reaction of all the fiscal instruments is similar to the productive public spending. We should note here that unproductive public spending exhibits higher persistence compared with productive public spending. This causes a different reaction of the economy and, in particular, of the fiscal rules. For example, in this case, the labour and capital taxes remain high for longer, while lump-sum transfers keep decreasing over time, all due to the high persistence of the shock. Lump-sum transfers decrease over time and the response of debt is much higher compared with the case of productive spending.

Moreover, from figure 2, we observe a significant crowding-out effect on private consumption because the persistent high taxes cause a significant negative wealth effect on consumers. Comparing the reaction of private consumption with the case with a positive shock to productive public spending, we note that, even in the case of the economy with nominal rigidities, we cannot get the empirically relevant positive reaction of private consumption. The assumption of price stickiness is not sufficient to drive the crowding-in effect on private consumption from an increase in public spending. The shift in labour demand is lower than in the case of the productive public spending shock. Accordingly, the response of real wage is negative, inducing a crowding-out effect on private consumption.

Our results are in line with Linnemann and Schabert (2003), who argued that price rigidities alone are not sufficient to generate a positive reaction in private consumption following a positive public spending shock. Moreover, we extend the argument of Schmitt-Grohé and Uribe (2004), where they implemented a model with nominal rigidities and "superficial" habits but cannot obtain the crowding-in effect on consumption. Our model contributes to this literature by showing that the combination of nominal rigidities with productive public spending can lead to a positive reaction in private consumption.

In the next section, we show the importance of public spending financing under the economy with nominal rigidities and the economy with flexible prices and wages.

6. Fiscal multipliers

In this section, we summarize the effects of the two types of public spending on the economy. The present-value multipliers are constructed following Leeper et al. (2010b) using the following equation:

$$\frac{\sum_{i=0}^{k}\left(\prod_{j=0}^{i} r_{t+j}^{-1}\right)\Delta X_{t+i}}{\sum_{i=0}^{k}\left(\prod_{j=0}^{i} r_{t+j}^{-1}\right)\Delta G_{t+i}^{c}}, \tag{19}$$

where X_{t+i} in tables 4 to 11 represents output (Y_{t+i}) and private consumption (C_{t+i}). We assess the effects of both categories of public spending. Thus, G_{t+i}^{c} denotes productive (G_{t+i}^{p}) and unproductive public spending (G_{t+i}^{u}). In addition, ΔX_{t+i} and ΔG_{t+i}^{c} are the relative level changes of the variables with respect to their steady-state values. Finally, the discount factor (r) represents the real interest rate.

Tables 4 and 5 present the cumulative present-value multipliers for output and consumption based on the mean estimates of the posterior distribution. The parameter k determines the period in quarters and is set up to 1,000 for the infinite horizon case. We also present the results on the impact of the exogenous shock, together with the results for 3, 5 and 10 years ahead. In addition, table 4 includes a column with the minimum and the maximum value of the respective multipliers.

Comparing the present value of output multipliers between the economy with and without nominal rigidities, in table 4 we can see that they are higher in the case of the economy with rigid prices and wages. Overall, our results are

TABLE 4

Present-value multipliers for output and consumption under productive and unproductive government spending shocks

Variable	Impact	1 year	3 years	5 years	10 years	∞	[min, max]
Economy with nominal rigidities							
Productive government spending present-value multipliers							
$\frac{\Delta Y_{t+i}}{\Delta G^p_{t+i}}$	1.051	1.047	1.000	0.961	0.905	0.854	[0.854, 1.055]
$\frac{\Delta C_{t+i}}{\Delta G^p_{t+i}}$	0.016	0.023	0.028	0.031	0.032	0.034	[0.016, 0.034]
Unproductive government spending present-value multipliers							
$\frac{\Delta Y_{t+i}}{\Delta G^u_{t+i}}$	0.992	0.946	0.886	0.846	0.785	0.674	[0.674, 0.992]
$\frac{\Delta C_{t+i}}{\Delta G^u_{t+i}}$	0.003	0.000	−0.002	−0.004	−0.008	−0.024	[−0.024, 0.003]
Economy without nominal rigidities							
Productive government spending present-value multipliers							
$\frac{\Delta Y^f_{t+i}}{\Delta G^p_{t+i}}$	0.850	0.732	0.590	0.517	0.447	0.424	[0.423, 0.850]
$\frac{\Delta C^f_{t+i}}{\Delta G^p_{t+i}}$	−0.006	−0.011	−0.017	−0.021	−0.025	−0.024	[−0.025, −0.006]
Unproductive government spending present-value multipliers							
$\frac{\Delta Y^f_{t+i}}{\Delta G^u_{t+i}}$	0.891	0.777	0.638	0.552	0.433	0.253	[0.253, 0.891]
$\frac{\Delta C^f_{t+i}}{\Delta G^u_{t+i}}$	−0.019	−0.036	−0.058	−0.074	−0.103	−0.156	[−0.156, −0.019]

TABLE 5

Present-value multipliers for output and consumption under productive and unproductive government spending shocks when only distortive taxes adjust and when only lump-sum transfers adjust

Variable	Impact	5 years	∞	Impact	5 years	∞
Economy with nominal rigidities						
	τ^l_t and τ^k_t adjust			Transfers adjust		
Productive government spending present-value multipliers						
$\frac{\Delta Y_{t+i}}{\Delta G^p_{t+i}}$	1.034	0.993	0.830	1.034	0.961	0.862
$\frac{\Delta C_{t+i}}{\Delta G^p_{t+i}}$	0.014	0.026	0.021	0.013	0.018	0.010
Unproductive government spending present-value multipliers						
$\frac{\Delta Y_{t+i}}{\Delta G^u_{t+i}}$	0.977	0.911	0.796	0.977	0.872	0.780
$\frac{\Delta C_{t+i}}{\Delta G^u_{t+i}}$	−0.004	−0.003	−0.011	−0.006	−0.031	−0.057
Economy without nominal rigidities						
	τ^l_t and τ^k_t adjust			Transfers adjust		
Productive government spending present-value multipliers						
$\frac{\Delta Y^f_{t+i}}{\Delta G^p_{t+i}}$	0.877	0.579	0.403	0.882	0.708	0.653
$\frac{\Delta C^f_{t+i}}{\Delta G^p_{t+i}}$	−0.006	−0.026	−0.078	−0.006	−0.017	−0.021
Unproductive government spending present-value multipliers						
$\frac{\Delta Y^f_{t+i}}{\Delta G^u_{t+i}}$	0.923	0.629	0.342	0.941	0.794	0.701
$\frac{\Delta C^f_{t+i}}{\Delta G^u_{t+i}}$	−0.017	−0.079	−0.120	−0.018	−0.056	−0.084

TABLE 6

Present-value (PV) multipliers for consumption under different nominal rigidities assumptions

	Economy	Productive government spending PV multipliers $\frac{\Delta C_{t+i}}{\Delta G^p_{t+i}}$	Unproductive government spending PV multipliers $\frac{\Delta C_{t+i}}{\Delta G^u_{t+i}}$
Impact		0.016	0.003
5 years	Benchmark	0.031	−0.004
∞		0.034	−0.024
Impact		0.015	0.003
5 years	Without price indexation	0.031	−0.002
∞		0.035	−0.023
Impact		0.016	0.003
5 years	Without wage indexation	0.031	−0.003
∞		0.035	−0.023
Impact		0.015	0.003
5 years	Without price and wage indexation	0.032	−0.002
∞		0.035	−0.023
Impact		0.008	−0.009
5 years	Without Calvo prices	0.017	−0.013
∞		0.023	−0.028
Impact		0.012	0.002
5 years	Without Calvo wages	0.021	−0.006
∞		0.026	−0.025
Impact		−0.002	−0.008
5 years	Without Calvo prices and wages	−0.001	−0.016
∞		0.008	−0.030

in the range of the values reported in previous empirical studies (see, for example, Monacelli and Perotti 2008).

Regarding consumption present-value multipliers under a positive shock to productive public spending for the economy with nominal rigidities, we observe that they are positive, both in the short run and in the long run.[35] In the case of a positive shock to unproductive public spending, we observe only an insignificant initial positive reaction to the consumption multiplier, which turns negative in the short run.

In terms of the economy with flexible prices and wages, our findings suggest a negative reaction of the consumption multiplier. Because firms can immediately adjust their prices in response to this shock, the shift in labour demand is weaker than the one in labour supply. As a consequence, the response of the aggregate wage is negative. It is evident that an increase in productive spending is not sufficient to generate the crowding-in effect on

35 This positive reaction of the consumption multiplier is statistically significant. This is shown in online appendix G, where we report the figures of the variables, including their confidence intervals.

TABLE 7

Present-value (PV) multipliers for consumption under different price setting assumptions

	Price setting	Productive government spending PV multipliers $\frac{\Delta C_{t+i}}{\Delta G^p_{t+i}}$	Unproductive government spending PV multipliers $\frac{\Delta C_{t+i}}{\Delta G^u_{t+i}}$
Impact		0.016	0.003
5 years	Benchmark	0.031	−0.004
∞		0.034	−0.024
Impact		0.011	−0.009
5 years	Rotemberg (1982) pricing	0.030	−0.007
∞		0.034	−0.026
Impact		0.014	−0.001
5 years	Rule-of-thumb pricing (Galí and Gertler 1999)	0.025	−0.008
∞		0.029	−0.026

TABLE 8

Present-value multipliers for output and consumption under productive and unproductive government spending shocks: Comparison between the two samples

Variable	Impact	1 year	3 years	5 years	10 years	∞	[min, max]
Sub-sample							
Productive government spending present-value multipliers							
$\frac{\Delta Y_{t+i}}{\Delta G^p_{t+i}}$	1.036	1.020	0.963	0.919	0.858	0.801	[0.801, 1.036]
$\frac{\Delta C_{t+i}}{\Delta G^p_{t+i}}$	0.013	0.019	0.023	0.024	0.025	0.026	[0.013, 0.026]
Unproductive government spending present-value multipliers							
$\frac{\Delta Y_{t+i}}{\Delta G^u_{t+i}}$	0.989	0.950	0.902	0.873	0.829	0.749	[0.749, 0.989]
$\frac{\Delta C_{t+i}}{\Delta G^u_{t+i}}$	0.000	−0.004	−0.006	−0.007	−0.010	−0.021	[−0.021, 0.000]
Full sample							
Productive government spending present-value multipliers							
$\frac{\Delta Y_{t+i}}{\Delta G^p_{t+i}}$	1.051	1.047	1.000	0.961	0.905	0.854	[0.854, 1.055]
$\frac{\Delta C_{t+i}}{\Delta G^p_{t+i}}$	0.016	0.023	0.028	0.031	0.032	0.034	[0.016, 0.034]
Unproductive government spending present-value multipliers							
$\frac{\Delta Y_{t+i}}{\Delta G^u_{t+i}}$	0.992	0.946	0.886	0.846	0.785	0.674	[0.674, 0.992]
$\frac{\Delta C_{t+i}}{\Delta G^u_{t+i}}$	0.003	0.000	−0.002	−0.004	−0.008	−0.024	[−0.024, 0.003]

NOTES: The top panel (Sub-sample) reports the output and consumption multipliers of the model estimated for the period 1963:Q2–2008:Q2, whereas the bottom panel (Full sample) shows the output and consumption multipliers of the model estimated for the period 1963:Q2–2013:Q4.

private consumption. On the other hand, the negative response of private consumption to the unproductive spending shock is much more pronounced than in the previous cases.

These results lead to the conclusion that nominal rigidities together with a positive shock to the productive component of government spending are essential for the replication of the empirically relevant crowding in of private consumption.

TABLE 9

Present-value (PV) multipliers for output and consumption under productive and unproductive government spending shocks with different shares of productive capital in the production function and different Frisch elasticities

	Economy with nominal rigidities	Productive government spending PV multipliers		Unproductive government spending PV multipliers	
		$\frac{\Delta Y_{t+i}}{\Delta G^{p}_{t+i}}$	$\frac{\Delta C_{t+i}}{\Delta G^{p}_{t+i}}$	$\frac{\Delta Y_{t+i}}{\Delta G^{u}_{t+i}}$	$\frac{\Delta C_{t+i}}{\Delta G^{u}_{t+i}}$
Impact		1.051	0.016	0.992	0.003
5 years	Benchmark	0.961	0.031	0.846	−0.004
∞		0.854	0.034	0.674	−0.024
Impact		1.036	0.016	0.984	0.004
5 years	$\alpha_3 = 0.05$	0.886	0.028	0.817	−0.003
∞		0.697	0.022	0.653	−0.021
Impact		1.044	0.015	0.981	−0.000
5 years	$\sigma^{l^*} = 5^*\sigma^l$	0.926	0.026	0.794	−0.020
∞		0.822	0.029	0.600	−0.048
Impact		0.984	0.007	0.899	−0.025
5 years	$\sigma^{l^{**}} = 50^*\sigma^l$	0.700	−0.006	0.474	−0.123
∞		0.652	0.003	0.187	−0.181

In order to assess if the method of financing the increased level of spending matters for the positive reaction of consumption, we consider different financing methods. Table 5 presents the cumulative present-value multipliers for output and consumption for two different cases. The left panel presents the case where only labour and capital taxes adjust to the exogenous public spending shock, whereas the right panel presents the case where only lump-sum transfers adjust.

Overall, we do not observe significant differences in the short run regarding the different methods of financing. However, in the long run, it matters more whether the government uses distortionary (such as labour and capital taxes) or non-distortionary (such as lump-sum transfers) methods of financing. This result is in line with the findings of Leeper et al. (2010b) who argued that distortionary taxation creates an additional channel that negatively affects the expansionary implications of increased public spending.

Regarding the economy with flexible prices and wages, we find that the present-value output multipliers are constantly higher for both productive and unproductive expenditures when only lump-sum transfers adjust to a positive spending shock. On the other hand, under the economy with nominal rigidities, output multipliers have very similar responses in the short run, as well as small differences in the long run.

Turning to the present value of consumption multipliers, in the case of the economy with flexible prices and wages, we observe significantly negative values when only labour and capital taxes adjust to productive and unproductive spending shocks. On the contrary, the differences between the two methods of financing are less pronounced under the economy with nominal rigidities. This

TABLE 10

Present-value (PV) multipliers for output and consumption under productive and unproductive government spending shocks with different specifications of the fiscal rules

	Economy with nominal rigidities	Productive government spending PV multipliers		Unproductive government spending PV multipliers	
		$\frac{\Delta Y_{t+i}}{\Delta G^p_{t+i}}$	$\frac{\Delta C_{t+i}}{\Delta G^p_{t+i}}$	$\frac{\Delta Y_{t+i}}{\Delta G^u_{t+i}}$	$\frac{\Delta C_{t+i}}{\Delta G^u_{t+i}}$
Impact		1.051	0.016	0.992	0.003
5 years	Benchmark	0.961	0.031	0.846	−0.004
∞		0.854	0.034	0.674	−0.024
Impact		1.069	0.018	1.012	0.010
5 years	$\gamma^j_{new} = 2 \times \gamma^j$	0.975	0.038	0.862	0.016
∞		0.897	0.043	0.687	−0.005
Impact		1.051	0.016	1.103	0.043
5 years	$\rho^{g^p} = \rho^{g^u} = 0.7918$	0.961	0.031	0.980	0.069
∞		0.854	0.034	0.702	0.022
Impact		0.948	0.003	0.992	0.003
5 years	$\rho^{g^p} = \rho^{g^u} = 0.9910$	0.791	0.004	0.846	−0.004
∞		0.691	0.010	0.674	−0.024
Impact	$\phi^{yg^p} = \phi^{yg^u} = 0.1191$	1.087	0.017	0.998	0.006
5 years		0.946	0.033	0.837	−0.002
∞	$\gamma^{bg^p} = \gamma^{bg^u} = 0.5240$	0.833	0.038	0.648	−0.028
Impact	$\phi^{yg^p} = \phi^{yg^u} = 0.2704$	1.048	0.015	0.998	0.002
5 years		0.950	0.029	0.878	−0.004
∞	$\gamma^{bg^p} = \gamma^{bg^u} = 0.3022$	0.836	0.032	0.735	−0.021

result may be explained by the stronger reaction of labour demand compared with the economy without nominal rigidities. As we have argued above, the larger shift in labour demand dominates the shift in labour supply, inducing an increase in the real wage and, in turn, private consumption rises. Accordingly, our results indicate that private consumption immediately increases when productive public spending rises, irrespective of the financing method, for the model with nominal rigidities only. In this regard, our findings extend the work of Linnemann and Schabert (2006) as we consider different fiscal policy rules, including those for capital and labour taxes.

In the next section we are going to present the main transmission mechanisms of public spending shocks in detail, including different consumption responses and comparing models with different features.

7. The role of nominal rigidities

In this section, we are going to show whether different methods of modelling nominal rigidities impact the key results of our analysis. As we mentioned above, nominal rigidities are the main element that induces a positive reaction of private consumption to a productive government spending shock. Our benchmark model assumes that prices and wages adjust at random intervals

TABLE 11

Present-value (PV) multipliers for output and consumption under productive and unproductive government spending shocks for the rigid economy with different values of the parameters in the Taylor rule

	Economy with nominal rigidities	Variable			
		Productive government spending PV multipliers		Unproductive government spending PV multipliers	
		$\frac{\Delta Y_{t+i}}{\Delta G^p_{t+i}}$	$\frac{\Delta C_{t+i}}{\Delta G^p_{t+i}}$	$\frac{\Delta Y_{t+i}}{\Delta G^u_{t+i}}$	$\frac{\Delta C_{t+i}}{\Delta G^u_{t+i}}$
Impact		1.051	0.016	0.992	0.003
5 years	Benchmark	0.961	0.031	0.846	−0.004
∞		0.854	0.034	0.674	−0.024
Impact		1.083	0.020	0.965	−0.006
5 years	$r^{\pi}_{new} = 0.5 * r^{\pi}$	1.041	0.042	0.843	−0.004
∞		0.917	0.043	0.658	−0.028
Impact		1.018	0.001	0.985	0.001
5 years	ρ_{new}=0.5*ρ	0.935	0.027	0.848	−0.003
∞		0.837	0.032	0.677	−0.023
Impact		1.056	0.016	0.992	0.003
5 years	$r^{y}_{new} = 0.5 * r^{y}$	0.982	0.033	0.839	−0.006
∞		0.882	0.038	0.671	−0.025
Impact		1.067	0.017	0.998	0.005
5 years	$r^{\Delta_y}_{new} = 0.5 * r^{\Delta_y}$	0.985	0.034	0.853	−0.001
∞		0.871	0.037	0.678	−0.022

of time in a staggered fashion, following the pricing mechanism introduced by Calvo (1983). In addition, we allow for prices and wages indexation.

In what follows we consider two main experiments. In the first experiment, we assess the relative importance of each of the nominal rigidities included in our model. More specifically, we consider the following versions of the model: without price indexation, without wage indexation, without both price and wage indexations, without Calvo price probabilities, without Calvo wage probabilities and without both Calvo price and wage probabilities. Table 6 summarizes the main findings of the different versions of our model in terms of nominal rigidities, which we compare with the benchmark case. Consumption multipliers are calculated on the impacts of the exogenous shocks, five years ahead and in the infinite horizon case.[36]

Our results show that price and wage indexations do not play a substantial role in terms of the response of private consumption to both productive and unproductive spending shocks. Indeed, in the models without these types of rigidities, consumption multipliers have very similar values as in the

36 We show the results for the consumption present-value multipliers because our aim is to assess consumption responses under different model assumptions. The results for output present-value multipliers are available upon request.

benchmark model. On the contrary, we find that Calvo price and wage probabilities significantly affect crowding-in and crowding-out effects. Removing one of these two nominal rigidities leads to lower values of consumption multipliers in response to both productive and unproductive spending shocks. Interestingly, when both Calvo prices and wages are excluded from the model, consumption multipliers for the productive government spending shock are negative for all the periods considered.

The second experiment that we perform relates to the comparison of different price setting frameworks. As we explained above, in our benchmark model we assume sticky prices and wages à la Calvo (1983). In the Calvo (1983) price setting model, each firm keeps its price fixed until it receives a random signal that it can change its price. When setting its price, the firm takes into account the prices other firms will charge until it has a chance to change its price again.

The first price setting alternative that we analyze is the Rotemberg (1982) framework for both prices and wages. In addition, we assume that prices and wages are partially indexed to past inflation rates. In the Rotemberg (1982) price setting model, the firm minimizes the cost of changing its price, weighted against the cost of being away from the price it would choose in the absence of adjustment costs. Under this assumption, the firm that adjusts its price entails convex costs.

The second alternative that we consider is "rule-of-thumb pricing" as in Galí and Gertler (1999). This price setting framework extends the basic Calvo (1983) model to allow for a subset of firms that use a backward-looking rule of thumb to set prices.[37] Accordingly, the coefficients of the hybrid Phillips curve derived from this model are function of two key parameters: the frequency of price adjustment and the fraction of backward-looking price setters.[38]

In table 7, we present the results of our simulated model with the benchmark (Calvo), first alternative (Rotemberg) and second alternative (rule of thumb) pricing settings, assuming degrees of price and wage rigidities consistent with our estimated model. In particular, we show the present-value

37 In particular, our benchmark model assumes that each firm receives the permission to optimally reset prices in a given period t with probability $1-\xi^p$. Firms that cannot change their prices keep their prices indexed to last period's inflation rate. Similarly, the rule-of-thumb pricing model assumes that each firm is able to adjust its price, in any given period, with a fixed probability $1-\xi^p$. However, the rule-of-thumb pricing model departs from our benchmark model because there are two types of firms. A fraction of firms, $1-\kappa^p$, that are forward-looking and set their prices optimally, and a fraction of firms, κ^p, that are backward-looking and use a simple rule of thumb that relies on past aggregate price behaviour.

38 The log-linearized equations for both wage and price equations under the three different price setting assumptions are reported in online appendix A.

multipliers for private consumption on the impacts of the exogenous shocks, five years ahead and in the infinite horizon case.[39]

Focusing on the comparison between Calvo and Rotemberg pricing mechanisms, our results indicate that private consumption increases in response to a productive government shock. The magnitude of such increase is very similar in both pricing setting mechanisms. We also observe that, with the Rotemberg pricing setting strategy, the negative response of private consumption to an unproductive spending shock is in line with the Calvo pricing mechanism. Hence, our results confirm the findings by Rotemberg (1987), Roberts (1995) and Ascari et al. (2011) showing that Calvo and the Rotemberg pricing schemes lead to the very same macroeconomic dynamics when models are linearly approximated assuming zero inflation in steady state.

Turning to the comparison between Calvo and rule-of-thumb pricing setting mechanisms, we observe similar results concerning the effects of increases in productive government spending on private consumption. In particular, impact, five years ahead and infinite horizon consumption multipliers are positive and show almost the same magnitude in both pricing mechanisms. We also find that present values of consumption multipliers in response to unproductive government expenditure shocks are negative under the two alternative pricing setting mechanisms. The main explanation of our results is that both the benchmark and rule-of-thumb pricing models provide very similar expressions for the Phillips curve, i.e., the so-called hybrid Phillips curve.[40] Therefore, we conclude that the main results of our analysis remain robust under different price setting frameworks.

8. Robustness checks

In this section we provide additional analysis in order to check the robustness of our findings. First, we focus on a sub-sample analysis in order to assess whether our estimated results are influenced by the Great Recession period. Second, we provide a sensitivity analysis of the benchmark model analyzing the relative importance of a few key parameters.[41]

39 Again, we present the results for only the consumption present-value multipliers. Results for output multipliers are available upon request.

40 In this regard, previous literature (see, for example, Galí and Gertler 1999 and Kiley 2007) has shown that the hybrid Phillips curve (in which current inflation is related to a lead of inflation, a lag of inflation, and marginal cost) has the best fit with the inflation dynamics in the US economy.

41 In the tables below, in order to save space, we do not report the results from the economy with flexible prices and wages but those are available upon request.

8.1. Sub-sample analysis

Our sample choice reflects the well-established hypothesis of a structural break in correspondence of the Great Recession (see, for example, Davig and Leeper 2011, Auerbach and Gorodnichenko 2012 and Bachmann and Sims 2012). Indeed, Great Recession has caused extraordinary contractions in US output, private investment and consumption as well as high unemployment. Following Christiano et al. (2015), we have estimated our model for the sub-sample 1963:Q2–2008:Q2, which coincides with pre-Great Recession period.[42] Table 8 presents the comparison of the output and consumption multipliers obtained from the estimates of the model for the full sample with those generated by the model for the sub-sample.[43]

Our results indicate that the present-value multipliers for output and consumption are broadly similar in the pre-Great Recession period and in the full sample that includes the post-Great Recession period. In this regard, previous literature has provided mixed results. For example, Ramey and Zubairy (2018) have shown that, during the Great Recession, government spending multipliers were not significantly different than during "normal" times. On the other hand, Christiano et al. (2011), using a medium-size DSGE model similar to ours, have found that the government spending multiplier can be very large when the nominal interest rate does not respond to an increase in government spending, that is, when the zero lower bound on the nominal interest rate binds.[44]

8.2. Sensitivity analysis

We start by examining how our key results are affected if we reduce the share of the productive public capital in the production process (α_3) to 0.05.[45] Table 9 shows that, when the share of public capital in the production process is reduced, the output present-value multipliers are lower, whereas the consumption present-value multipliers are very similar to the benchmark case.

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42 In the estimation of the model for the sub-sample, we used the period 1960: Q1–1963:Q1 as the pre-sample.

43 We acknowledge that the relevant comparison should be between the pre-recession period and the recession period itself. However, we refrained from estimating our model for the sample period 2008:Q3–2013:Q4 as the short length of such sample (21 observations) would imply inaccurate empirical results.

44 Christiano et al. (2011) have obtained this result by using a computationally efficient solution algorithm that respects the non-linearity in the Taylor rule but log-linearizes the remaining equilibrium conditions.

45 Note that there is no consensus regarding the value of this parameter in the related literature, which contains a suggested range of values between 0.05 and 0.24 (see Leeper et al. 2010b).

The second experiment relates to different values for the Frisch elasticity. As we mentioned in section 4.2, our benchmark value is in the lower range of estimates reported in the related literature. Therefore, in this experiment, we increase the Frisch elasticity 5 and 50 times, so as to capture a medium and a high value for Frisch elasticity. As we can see from table 9, the higher the Frisch elasticity, the lower the crowding-in effect and output multipliers are after a positive shock to productive public spending. Even if we increase the Frisch elasticity significantly, we still get a crowding-in of private consumption in the short run. In the case of an increase in unproductive public spending, the multipliers of output and consumption decrease as we increase the Frisch elasticity.

Now we focus on the speed of adjustment to debt of the various fiscal rules (γ^j parameter, where $j = bl$, bk, bg^p, bg^u and bt). In particular, we assess the effects to our economy when all the rules adjust twice as fast in each shock compared with the benchmark case (table 10). The results indicate that, under the economy with nominal rigidities, the present-value multipliers for output and consumption are higher compared with the benchmark case. This indicates that the economy benefits more in the short run and long run when the government does not postpone the repayment of debt via prolonged taxation, thereby leading to a lower negative wealth effect.

Moreover, table 10 presents two alternative values for the persistence of the government spending shocks. One case assumes that both productive and unproductive expenditure shocks have the same high persistence and the second assumes that they have the same low persistence. As we can see from table 10, when both shocks have the same low persistence, the crowding-in effect on private consumption is evident even for the unproductive public spending case. When both ρ^{g^p} and ρ^{g^u} are equal to 0.984, the response of private consumption is still positive under productive public spending both in the short run and long run, but at a lower magnitude. These results are fairly intuitive because in our model, higher future spending will be financed via higher taxes. Therefore, there is a stronger wealth effect that affects households negatively and reduces the crowding-in effects of private consumption.

In table 10, we also report two experiments where the parameters of both productive and unproductive spending rules are initially set equal to the values of the productive fiscal rule and, successively, equal to the values of the unproductive fiscal rule. The results indicate a moderately higher crowding-in on private consumption, mainly in the long run, if we set both rules equal to the productive public spending rule. This result is driven from the fact that the productive expenditure adjusts faster to debt deviations, minimizing the negative wealth effects from future taxation, as discussed previously.

Finally, we focus on the effects of public spending shocks under several monetary policy approaches. In table 11, we consider different values for the parameters of the Taylor rule (i.e., r^{π}, ρ, r^{y} and r^{Δ_y}). In particular, we analyze output and consumption multipliers when these parameters are set to the half of their respective estimated values. A less aggressive monetary policy implies lower nominal and real interest rates, weakening consumers' incentives to postpone consumption and, in turn, boosts final output.

Thus, lower values of the parameters indicating the response of nominal interest rate to inflation and output gap (i.e., r^{π}, r^{y} and r^{Δ_y}) cause higher values for output and consumption multipliers. For the case where we have a decrease in the interest rate smoothing parameter, leading to a higher response of the nominal interest rate, we observe a smaller response of output and consumption multipliers compared with the other cases and the benchmark.

9. Conclusion

In this paper, we developed and estimated a new Keynesian DSGE model with productive and unproductive government spending and various fiscal rules. In particular, we have assumed that the productive government expenditure enters firms' production function. Our model has been estimated with Bayesian techniques for the sample period 1963:Q2–2013:Q4 and was able to match the moments of key variables in the US data for that period.

Our main findings indicated that private consumption will increase, in the short run and long run, only if there is an increase in the productive component of public spending under the presence of nominal rigidities. This result was driven by the stronger shift in labour demand compared with labour supply and the high inflation that led to an increase in wage rates. On the contrary, we found that unproductive public spending exhibits high persistence, leading to prolonged distortionary taxes and a strong negative wealth effect that is sufficient to crowd out private consumption.

Our results contribute to the related literature in several other ways. First, our estimated fiscal rules show that the capital tax response is more procyclical than the labour tax response. Similarly, capital tax responds more strongly than labour tax to changes in government debt. Thus, capital tax is used as a shock absorber, while labour tax is held relatively smooth over the business cycle. Second, we found that lump-sum transfers exhibit a strong reaction to changes in debt-to-output ratio. Third, our estimates show that unproductive expenditure responds more strongly than productive spending to changes in government debt, indicating that policy-makers are reluctant to raise taxes to finance "unpopular" public spending. Therefore, they prefer to issue new debt. Last, we found that the estimated parameter for the persistence of the unproductive spending shock is higher than the one of productive expenditure, which is also one of the key reasons for the crowding-in effect on private consumption.

Our approach allowed us to assess several fiscal policy experiments. In particular, our results show that, when the share of public capital in the production process is reduced, all the present-value multipliers decrease. We found that, for the economy with nominal rigidities, when the fiscal rules adjust more rapidly to debt deviations and/or at a lower persistence than in the estimated model, the crowding-in effect on private consumption is more pronounced. Finally, our findings suggest that a less aggressive monetary policy implies lower nominal and real interest rates, weakening consumers' incentives to postpone consumption and, in turn, leads to higher GDP.

Supporting information

Supplementary material accompanies the online version of this article.

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