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# Endogenous Technology, Scarring and Fiscal Policy

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**Abstract**

This paper studies fiscal policy in a New Keynesian DSGE model with endogenous technology growth in which scarring can occur endogenously through hysteresis effects in TFP. Both demand- and supply-driven recessions can weaken investment in R&D and technology adoption, thus depressing the long-run trend. Fiscal policy has long-term effects under endogenous growth and the type of fiscal stimulus is decisive for the sign and magnitude of fiscal multipliers. Expansionary government spending boosts output transitorily but over time crowding out in technology-enhancing investment weakens the long-run trend. I introduce fiscal growth policies in this environment which in the short run raise aggregate demand and simultaneously support growth-enhancing investment and thus the long-run trend, generating a positive trend multiplier. Multipliers of fiscal growth policies can be sizeable, above all when targeted to R&D, which is characterized by fiscal multipliers greater than unity. The importance of monetary-fiscal interaction is amplified due to long-run non-neutrality of monetary policy.

**JEL Classification:** E24, E31, E32, E52, E62, O42

**Keywords:** Fiscal Multiplier, Hysteresis, Endogenous Growth, Inflation, Monetary-Fiscal Interaction

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# 1. Introduction

Fiscal policy is typically studied based on New Keynesian models with exogenous total factor productivity. In this environment, the long-run trend is not endogenously modeled and, consequently, cyclical fluctuations do not affect the long-term aggregate output path. A growing literature, however, emphasizes the importance of hysteresis effects through cycle-trend interaction and long-run scars of recessions, as illustrated in Figure 1 by example of real GDP dynamics in the euro area.

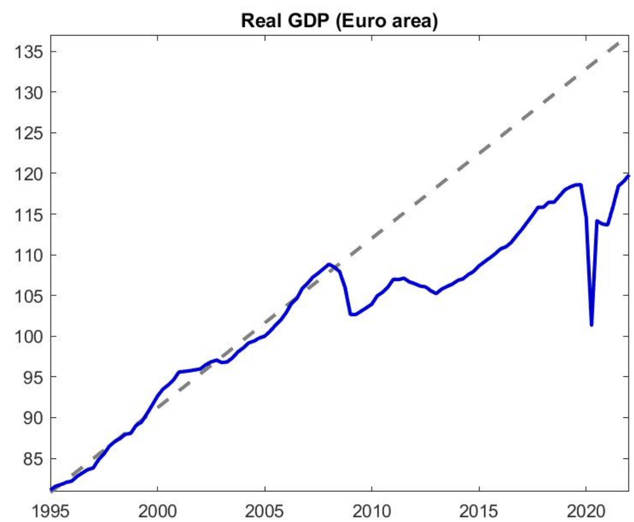


Figure 1: Euro area real GDP and post-crises trend shift

The mechanisms and scope of fiscal policy under endogenous growth in which scarring effects can occur endogenously have thus far not been studied by the previous literature as the latter studies fiscal policy based on models with exogenous long-run trend. This paper bridges this gap and studies fiscal policy in a rich medium-scale DSGE model with endogenous technology growth through R&D and technology adoption in which long-run trend dynamics are endogenously modeled and output hysteresis can occur in general equilibrium. This analysis constitutes thus to the best of my knowledge the first paper to study the dynamics and fiscal multipliers of fiscal policy tools from the perspective of a New Keynesian model with endogenous long-run trend through productivity-enhancing investment.

As to the main model characteristics, the model features an endogenous long-run trend as technology growth is modeled endogenously in general equilibrium as the result of investment in R&D and technology adoption (Comin and Gertler (2006)).[1] In this environment, I study government spending and, in addition and novel to the New Keynesian model, fiscal growth policies under which fiscal spending is directly targeted to R&D or technology adoption investment. Monetary policy may be constrained by the zero lower bound on nominal interest rates.

In this model, scarring effects can result endogenously as recessions weigh on technology-enhancing investment, generating a procyclical slowdown of total factor productivity and thus of the long-run trend. These described hysteresis effects in TFP can generate long-lasting slumps with permanent output losses. I show that scarring can occur following demand- as well as supply-driven recessions.

The following key results as to the role of fiscal policy under endogenous growth emerge. First, fiscal policy has long-run effects under endogenous growth. Second, the type of fiscal stimulus is decisive for the sign and magnitude of the multiplier over the short and long run. Specifically, government spending is subject to *long-run crowding out* as it crowds out not only investment in physical capital as in standard models but also investment in R&D and technology adoption. The expansionary effect of government spending is confined to the short run, while it weighs on the long-run trend path over time and thus intensifies scarring effects when implemented in a recession. Further, I introduce novel fiscal policy tools in the DSGE context in the form of fiscal growth policies directly targeted to the R&D or the technology adoption sector. While well-established in the endogenous growth literature with respect to long-run growth, fiscal growth policies have a new role in the New Keynesian model, as they act as short-run demand stabilization tools, while simultaneously boosting the long-run trend path. Further, fiscal growth policies are disinflationary and constitute thus also effective tools for reducing scarring in supply-driven recessions when monetary policy faces a trade-off between inflation and output stabilization.

[1] This approach of modeling endogenous TFP dynamics is consistent with the previous literature on output hysteresis through total factor productivity in New Keynesian DSGE models (see Moran and Queralto (2018), Anzoategui et al. (2019), Ikeda and Kurozumi (2019), Elfsbacka Schmöller and Spitzer (2021)).

I quantify these results further by studying fiscal multipliers in this environment. The government spending multiplier peaks on impact but over time crowding out in technology-enhancing investment counteracts the initial expansionary effect and weighs on cumulative fiscal multipliers. Growth-enhancing policies build up gradually over time and are subject to sizeable cumulative fiscal multipliers. This applies above all to R&D which generates multipliers above unity. I introduce the concept of the trend multiplier which measures the permanent output losses resulting from the policy-induced shift in the long-run trend. The trend multiplier of government spending is negative, reflecting a permanent fall in the long-run trend component of -0.3% relative to the pre-shock trend. Fiscal growth policies generate positive trend multipliers, indicating an upward shift in the long-run trend of +0.7% for technology adoption and of +1.4% in the case of R&D. Since these trend effects enter additively, fiscal policy is thus subject to sizable cumulative effects on aggregate output and, ultimately, on aggregate income.

Lastly, I show that the role of monetary-fiscal interaction is substantially amplified, resulting from the inherent long-run non-neutrality of monetary policy under endogenous growth. Firstly, the underlying monetary policy strategy is a key determinant for the size of fiscal multipliers. When monetary policy is conducted in the form of an inflation-based make-up strategy, specifically price level targeting (PLT), expansionary government spending will be met by a more restrictive monetary policy response due to the commitment to revert inflationary pressures and to align the price level with target. This response amplifies long-run crowding out effects. Due to the disinflationary effect of fiscal growth policies, they are under PLT met by a relatively more accommodative monetary policy response. The latter generates an additional boost to growth-promoting investment relatively to the inflation targeting regime. As to the role of the ZLB in this context, long-run crowding out of government spending prevails also under constrained monetary policy, albeit to a lesser extent. Fiscal growth policies, in turn, are effective in counteracting the long-run scars of ZLB episodes and in supporting liftoff from the ZLB.

**Previous literature:**

Earlier work studies government spending from the lens of stationary New Keynesian models with increased persistence as TFP transitorily fluctuates with hours worked (D'Alessandro et al. (2019); Engler and Tervala (2018)), or technology utilization (Jørgensen and Ravn (2022)) around a constant level. Differently to these models, this framework features long-run growth. Moreover, the long-run trend is modeled endogenously and fully microfounded through technology-enhancing investment. In this paper, recessions can generate not only persistent but permanent output losses and fiscal policy exerts permanent, long-run effects on aggregate output. In addition, I introduce and study fiscal growth policies directly targeted to technology-enhancing investment as novel stabilization tools.

This paper is closely linked to the literature on macroeconomic models with endogenous total factor productivity growth which studies the interaction between cycle and long-run trend and hysteresis effects (see Cerra et al. (2020) for a review)[2] in this context. Recent estimated medium-scale DSGE models with endogenous technology growth (Moran and Queralto (2018); Anzoategui et al. (2019); Bianchi et al. (2019); Elfsbacka Schmöller and Spitzer (2021)) emphasize the role of a crisis-induced deceleration in TFP growth in explaining the depth and persistence of recent recessions and the simultaneously observable intensification of the productivity slowdown. By means of Keynsian growth models Benigno and Fornaro (2018) show how demand shortfalls can lead into stagnation as a combination of a growth trap and a liquidity trap and Fornaro and Wolf (2020) study the possibility of long-run scars of supply-side disruptions as in the COVID-19 crisis.

The recent literature also provides empirical evidence on the long-term effects of monetary and fiscal policy. Elfsbacka Schmöller and Spitzer (2021) show that depressed aggregate demand in the context of the euro area sovereign debt crisis significantly intensified the hysteresis effects in TFP, the depth of the recession and weakness of the subsequent recovery. Ilzetzki (2022) presents direct, causal empirical evidence on the positive effect of stimulus to aggregate demand through fiscal policy on total factor productivity growth. Antolin-Diaz and Surico (2022) and Cloyne et al. (2022) provide empirical evidence on the long-term effects of government spending and of personal and corporate tax changes respectively. Regarding monetary policy, Jordà et al. (2022) provide empirical evidence on the long-run effects of monetary policy on the productive capacity of the economy. Moran and Queralto (2018) give further empirical evidence supportive

[2] Furlanetto et al. (2021) and Aikman et al. (2022) provide empirical evidence on hysteresis effects.

of the the persistent effects of monetary policy shocks on TFP growth. Elfsbacka Schmöller and Spitzer (2022) theoretically study the role of long-run non-neutrality for the conduct and operating environment of monetary policy under endogenous growth and the implications for the design of monetary policy strategies under low $r^*$.

This paper is structured as follows. Section 2 presents the model. Section 3 studies fiscal policy under endogenous growth. Section 4 analyzes the scarring effects of recessions. The role of monetary-fiscal interaction is studied in section 5. Section 6 concludes.

# 2. Model

This section describes the theoretical model framework. The main model backbone constitutes a medium-scale New Keynesian DSGE model in the spirit of Christiano et al. (2005) and Smets and Wouters (2007). In addition, the model features an endogenous technology growth mechanism (Comin and Gertler (2006)), introducing endogenous trend growth. Growth occurs in the form of expanding varieties of intermediate goods (Romer (1990)), driven by costly investment in research and development and technology adoption. Fiscal policy is studied in the form of standard government spending and, novel to the New Keynesian model, in the form of fiscal growth policies directly targeted to the innovation sectors.

## 2.1 Endogenous Technology Growth

The model features endogenous trend growth resulting from endogenous total factor productivity dynamics, following the mechanism in Comin and Gertler (2006). Technological progress evolves as a two-stage process of research and development and technology adoption. R&D investment generates new innovations, increasing the total technology stock $Z_t$. For new technologies to translate into total factor productivity gains they have to be adopted in production which is costly. The corresponding stock of adopted technologies is denoted by $A_t$. The resulting, aggregate production function can be represented as

$$Y_t = \theta_t A_t^{\frac{1}{\vartheta-1}} K_t^{\alpha} L_t^{1-\alpha}. \tag{1}$$

$A_t^{\frac{1}{\vartheta-1}}$ refers to the endogenous component of total factor productivity and $\theta_t$ to the standard technology shock.[3]

### 2.1.1 R&D sector

Technology growth occurs in the form of an expansion in the varieties of intermediate goods as in Romer (1990) which are invented as the result of investment in research and development by innovators. The latter sell the right to use a newly invented technology to the adoption sector (section 2.1.2) which converts new innovations into technologies usable in production. Time $t$ technology frontier is defined by the stock of technologies $Z_t$. The latter may become obsolete at the exogenous rate $1-\phi$. The law of motion of the technology stock can then be stated as the sum of newly invented technologies $\varphi_t X_t$ and of the non-obsolete technologies from time $t$, $\phi Z_t$:

$$Z_{t+1} = \phi Z_t + \varphi_t X_t. \tag{2}$$

New technologies are created through the production technology of innovator $i$

$$\varphi_t X_t^i, \tag{3}$$

where $X_t^i$ denotes R&D investment by innovator $i$, measured in units of final output, and $\varphi_t = \frac{\chi Z_t}{Z_t^{\zeta} X_t^{1-\zeta}}$ and total R&D investment in the economy equals to $X_t = \int_i X_t^i di$. The innovation process entails thus a positive spillover from the aggregate stock of technologies $Z_t$ to the productivity of an individual innovator. The R&D process is further characterized by an externality from aggregate R&D efforts $\frac{1}{Z_t^{\zeta} X_t^{1-\zeta}}$, with $0 < \zeta < 1$ denotes the R&D elasticity of the aggregate creation of new technologies, ensuring stationarity. The R&D efficiency parameter $\chi$

[3]Technically, total factor productivity in this framework is thus the combination of the endogenous trend component $A_t$ and the standard technology shock $\theta_t$. The latter is, among others, used in section 4 as the trigger of the supply-driven recession scenario.

is calibrated to match the respective long-run growth rate, i.e. the rate of technology growth prevailing on the balanced growth path.

Let $J_t$ denote the value of an undadopted technology, i.e. of a technology which has been invented but not yet incorporated in production through technology adoption. The government may commit to pay a fixed share of the expenditures on R&D $s_t^{RD}$.[4] Technologies created at time $t$ are available from the subsequent period. Innovator $i$'s problem can then be summarized as

$$\max_{\{X_{i,t+j}\}_{j=0}^{\infty}} \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \Lambda_{t,t+1+j} \left[ J_{t+1+j}\varphi_{t+j} X_{i,t+j} - \left(1 - s_t^{R\&D}\right) \left(1 + f^x \left( \frac{X_{i,t+j}}{X_{i,t+j-1}} \right) \right) X_{i,t+j} \right] \right\},$$

where $\Lambda_{t,t+1+j}$ denotes the discount factor of the household. R&D is subject to adjustment costs modeled by means of the convex function $f^x(\cdot)$ with the following properties. On the balanced growth path applies that $f^x\left(\frac{\bar{X}^i_{t+1}}{\bar{X}^i_t}\right) = f^{x\prime}\left(\frac{\bar{X}^i_{t+1}}{\bar{X}^i_t}\right) = 0$, where $\frac{\bar{X}^i_{t+1}}{\bar{X}^i_t} = 1 + g$ and $g$ denotes the long-run growth rate of R&D investment and hence of total factor productivity and output. Given symmetry, dropping subscript $i$, the corresponding optimality condition states that the marginal gains from R&D investment, i.e. the value of an unadopted technology at $t+1$ discounted to the current period, equals marginal costs:

$$\mathbb{E}_t \left( \Lambda_{t,t+1} J_{t+1} \varphi_t \right) = \left(1 - s_t^{RD}\right) \Delta f^x \tag{5}$$

with $\Delta f^x = 1 + f^{x\prime}\left(\frac{X_t}{X_{t-1}}\right)\frac{X_t}{X_{t-1}} + f^x\left(\frac{X_t}{X_{t-1}}\right) - \mathbb{E}_t\, \Lambda_{t,t+1} f^{x\prime}\left(\frac{X_t}{X_{t-1}}\right)\left(\frac{X_t}{X_{t-1}}\right)^2$.

Time $t$ innovation, i.e. the creation of new technologies, can be derived from $V_t = \int_i V_t^i di = \chi Z_t^{1-\zeta} X_t^{\zeta}$, where $\zeta$ denotes the elasticity of innovation $V_t$ to aggregate R&D investment. We now turn to the implications for the determinants of growth in the model. The growth rate of the technology stock $\frac{Z_{t+1}}{Z_t}$ can be derived as $\phi + \chi\left(\frac{X_t}{Z_t}\right)^{\zeta}$, which also demonstrates that the long-run growth rate of innovation is endogenous in this framework and shifts in the ratio $\frac{X_t}{Z_t}$ induce permanent changes in the long-run growth rate.

[4] $s_t^{RD}$ follows an AR(1) process with mean zero, as described in section 3.

#### 2.1.2 Technology adoption

New, invented technoloies by the R&D sector do not immediately translate into increases in TFP. Instead, they first have to be adopted, which captures realistic lags in terms of the diffusion of innovations to the wider economy. The process and underlying decision of technology adoption, i.e. the conversion of new technologies into technologies which can be utilized in the production process, is performed by a competitive adoption sector.[5] $\lambda_t$ refers to the probability that an individual innovator is successful in making a technology usable in firms' production at time $t$. The adoption probability is increasing in adoption expenditures $E_t$.

Adoption investment is subject to adjustment costs[6]. The technology adoption process requires specialized input $E_t$, i.e. equipment, which is converted from final output and acquired at price $Q_t^a$. The adoption probability $\lambda_t$ is increasing in the used equipment- or investment-used by the respective adopter $E_t^i$ and evolves according to

$$\lambda_t \left(E_t^i\right) = \kappa_\lambda \left(\frac{X_t}{A_t}\right)^\eta \left(E_t^i\right)^{\rho_\lambda} . \tag{6}$$

The underlying assumption as to the adoption parameters are $\kappa_\lambda > 0$, $0 < \eta < 1$ and $0 < \rho_\lambda < 1$ and the technology adoption probability is thus increasing and concave in the adoption investment. Note that the adoption rate entails a spillover term from aggregate spending on R&D $X_t$[7] and the spillover parameter $\eta$. The spillover models the realistic property of aggregate R&D efforts exercising a positive effect on the probability of adopting new technologies as, for example, the adoption sector learns from R&D activities.

Technology adopters acquire the rights to use an unadopted technology from the R&D sector at the competitive price $J_t$. In case of successful adoption, the adopter sells the technology at

[5] By modeling the adoption decision by means of an adoption sector allows for an endogenous diffusion process while at the same time keeping the model parsimonious. In doing so, aggregation is simplified as the adoption probability is identical for each technology and thus the need to follow the fraction of firms which have adopted the respective technologies is avoided.

[6] Note that the adjustment cost function of technology adoption is modeled following the adjustment costs for capital producers, as described in section 2.4. They differ though in the magnitude of the adjustment costs, as discussed in section 2.10.

[7] The spillover term is adjusted for $A_t$ for stationarity purposes.

price $H_t$ which follows

$$H_t = \Pi_t + \phi \mathbb{E}_t \left( \Lambda_{t,t+1} H_{t+1} \right). \tag{7}$$

Based on this, the technology adoption problem can be derived as

$$J_t = \max_{E_t^i} -Q_t^a \left(1 - s^{ta}\right) E_t^i + \phi \mathbb{E}_t \left\{ \Lambda_{t,t+1} \left[ \lambda_t \left(E_t^i\right) H_{t+1} + \left(1 - \lambda_t \left(E_t^i\right)\right) J_{t+1} \right] \right\}. \tag{8}$$

Hence, adopters equate the costs of adoption against the respective expected gains. The latter equal to the sum of the value of unadopted and adopted technologies, weighted by the respective probability. The government may commit to pay a fixed share of technology adoption expenditures $s_t^{ta}$.[8] Since adoption effort will be identical across technologies ($E_t^i = E_t$), subscript $i$ can be omitted and the optimality condition for adoption derived as

$$\rho_\lambda \kappa_\lambda \phi \left( \frac{X_t}{A_t} \right)^\eta \mathbb{E}_t \left[ \Lambda_{t,t+1} \left( H_{t+1} - J_{t+1} \right) \right] = \left(1 - s_t^{ta}\right) Q_t^a E_t^{1-\rho_\lambda}. \tag{9}$$

Aggregate adoption investment follows as the product of the investment in technology adoption $E_t$ and the stock of unadopted technologies $(Z_t - A_t)$ and hence corresponds to $(Z_t - A_t) E_t$. Finally, the law of motion for adopted technologies and hence endogenous total factor productivity in time $t+1$ can be derived as the sum of the non-obsolete adopted technologies and the newly adopted technologies from time $t$

$$A_{t+1} = \phi \left[ A_t + \lambda_t \left( Z_t - A_t \right) \right]. \tag{10}$$

## 2.2 Final good production

The economy features two types of firms, intermediate goods producers and final goods producers which use intermediate goods as inputs. There is a continuum of measure unity of monopolistically competitive final goods producers. Final good firm $i$ produces differentiated output $Y_t^i$. The final good composite is a CES aggregate of the respective differentiated final

[8] $s_t^{ta}$ follows an AR(1) process with zero mean, as described in section 3.

goods

$$Y_t = \left[\int_0^1 Y_t^{i\,\frac{\mu-1}{\mu}} di\right]^{\frac{\mu}{\mu-1}}. \tag{11}$$

The price level of final output is $P_t = \left[\int_0^1 P_t^{i\,1-\mu} di\right]^{\frac{1}{1-\mu}}$, where $P_t^i$ is the price set by final good producer $i$. Output by final goods producer $i$'s output is derived from cost minimization and equals to

$$Y_t^i = \left(\frac{P_t^i}{P_t}\right)^{-\mu} Y_t. \tag{12}$$

Prices are subject to Calvo price rigidities, where each final good firm can adjust its price with probability $1-\xi^p$. An indexation rule models the price adjustment by firms which cannot adjust their price

$$P_t^i = P_{t-1}^i \pi_{t-1}^{\iota_p} \bar{\pi}^{1-\iota_p}. \tag{13}$$

The price indexation parameter is denoted by $\iota_p$, time $t$ inflation by $\pi_t = \frac{P_t}{P_{t-1}}$ and steady state inflation by $\bar{\pi}$. Final good firms are subject to nominal marginal costs in the form of intermediate good input price $P_t^m$. The final good producer makes the choice about the optimal reset price $P_t^*$ subject to final good demand (12) according to

$$\max_{P_t^*} \mathbb{E}_t \sum_{j=0}^{\infty} \xi_p^j \Lambda_{t,t+j} \left(\frac{P_t^* \prod_{k=1}^j \pi_{t+k-1}^{\iota_p} \bar{\pi}^{1-\iota_p}}{P_{t+j}} - \frac{P_{t+j}^m}{P_{t+j}}\right) Y_{t+j}^i. \tag{14}$$

## 2.3 Intermediate goods production

As described in section 2.1, total factor productivity growth occurs in the form of expanding varieties $A_t$ of intermediate goods. Intermediate products $A_t$ are produced by monopolistically competitive producers, where $Y_t^{im}$ denotes output produced by intermediate good producer $i$. The composite of intermediate goods $Y_t^m$ which is used as input by final good firms:

$$Y_t^m = \left[\int_0^{A_t} \left(Y_t^{im}\right)^{\frac{\vartheta-1}{\vartheta}} di\right]^{\frac{\vartheta}{\vartheta-1}}. \tag{15}$$

$P_t^{im}$ denotes the nominal price set by producer $i$ and the price of the intermediate good composite equals to $P_t^m = \left[\int_0^{A_t} \left(P_t^{im}\right)^{1-\vartheta} di\right]^{\frac{1}{1-\vartheta}}$. Intermediate good firms use labor and capital as inputs and produce by means of a Cobb-Douglas production technology:

$$Y_t^{im} = \theta_t \left(K_t^i\right)^{\alpha} \left(L_t^i\right)^{1-\alpha}, \tag{16}$$

where $\theta_t$ equals to a standard technology shock and thus the exogenous component of total factor productivity. $W_t$ equals to the nominal wage and $R_t^k$ to the rental rate of capital. The optimality conditions of intermediate goods producers' cost minimization are:

$$\alpha \frac{\vartheta - 1}{\vartheta} \frac{P_t^m}{P_t} \frac{Y_t^m}{K_t} = R_t^k \tag{17}$$

$$(1-\alpha) \frac{\vartheta - 1}{\vartheta} \frac{P_t^m}{P_t} \frac{Y_t^m}{L_t} = W_t. \tag{18}$$

$\frac{\vartheta}{\vartheta-1}$ describes the markup owed to imperfect competition in the intermediate goods sector and $\frac{P_t}{P_t^m}$ the the markup of the price of final relatively to the price of the intermediate good composite $P_t^m$ respectively.

As shown in section 2.1, intermediate good profits are a key are determinant of investment in R&D (2.1.1) as well as in technology adoption (section 2.1.2). Intermediate goods profits are equal for all firms ($\Pi_t^i = \Pi_t$) and derive as

$$\Pi_t = \frac{1}{\vartheta} \frac{P_t^m}{P_t} \frac{Y_t^m}{A_t}. \tag{19}$$

$K_t = \int_0^{A_t} K_t^i di$ and $L_t = \int_0^{A_t} L_t^i di$ are the conditions for market clearing in factor markets. From (16)-(18) follows aggregate intermediate good output[9] :

$$Y_t^m = \theta_t A_t^{\frac{1}{\vartheta-1}} K_t^{\alpha} L_t^{1-\alpha}. \tag{20}$$

[9]To a first order $Y_t = Y_t^m$ holds.

## 2.4 Capital producers: investment

Capital producers transform final output to physical capital $K_t$ which is sold to households at price $Q_t$, where capital is subject to adjustment costs $f_i$.[10] The representative capital producer chooses the $\{I_{t+j}\}_{j=0}^{\infty}$ in order to maximize expected discounted profits

$$\mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left[ Q_{t+j} I_{t+j} - \left( 1 + f_i \left( \frac{I_{t+j}}{I_{t+j-1}} \right) \right) I_{t+j} \right] \right\}. \tag{21}$$

From profit maximization obtains that the marginal costs of the generation of investment goods is equal to the respective price:

$$Q_t = 1 + f_i \left( \frac{I_t}{I_{t-1}} \right) + \frac{I_t}{I_{t-1}} f_i' \left( \frac{I_t}{I_{t-1}} \right) - \mathbb{E}_t \left[ \Lambda_{t+1} \left( \frac{I_t}{I_{t-1}} \right)^2 f_i' \left( \frac{I_t}{I_{t-1}} \right) \right]. \tag{22}$$

Lastly, the law of motion for capital equals to

$$K_{t+1} = (1 - \delta) K_t + I_t. \tag{23}$$

## 2.5 Employment agencies

A continuum of households monopolistically supply specialized labor $L_t^i$. As in Erceg et al. (2000), a large number of competitive employment agencies transform specialized labor to a homogeneous input $L_t$. $L_t$ is used in intermediate goods production and equals to

$$L_t = \left[ \int_0^1 L_t^{i \frac{\omega-1}{\omega}} di \right]^{\frac{\omega}{\omega-1}}. \tag{24}$$

The cost minimization of employment agencies delivers the labor demand for type $i$:

$$L_t^i = \left( \frac{W_t^i}{W_t} \right)^{-\omega} L_t, \tag{25}$$

[10] Note that the adjustment cost functions $f_i$, $f_x$ and $f_a$ are analogous but differ in the magnitude of adjustment costs (see section 2.10).

where the nominal wage of $i$ equals to $W_t^i$. The aggregate wage at which the labor composite is bought by intermediate goods firms equals to

$$W_t = \left[ \int_0^1 W_t^{i\,1-\omega} di \right]^{\frac{1}{1-\omega}}. \tag{26}$$

## 2.6 Households

The household problem can be characterized as follows. Household $i$ maximizes utility

$$\mathbb{E}_t \left\{ \sum_{j=0}^{\infty} \beta^j \left[ log\left(C_{t+j} - hC_{t+j-1}\right) - \frac{\psi}{1+\nu} L_{i,t+j}^{1+\nu} \right] \right\} \tag{27}$$

respect to the budget constraint

$$\frac{W_t^i}{P_t} L_t^i + R_t \frac{B_t}{P_t} + \left( R_t^k + (1-\delta) Q_t \right) K_t + \Pi_t = C_t + \frac{B_{t+1}}{P_t} + Q_t K_{t+1}, \tag{28}$$

where $C_t$ equals consumption and $h$ habit persistence $(0 < h < 1)$.[11] $B_t$ states nominal riskless bonds. A fraction $1 - \xi_w$ of households can adjust their wage in period $t$. The optimal wage follows from

$$\max_{W_t^*} \mathbb{E}_t \sum_{j=0}^{\infty} \left\{ (\xi_w \beta)^j \left[ \frac{U_{c,t+j}}{P_{t+j}} L_{t+j}^i W_t^* \prod_{k=1}^{j} (1+g)\, \pi_{t+k-1}^{\iota_w} \bar{\pi}^{1-\iota_w} - \frac{\psi}{1+\nu} \left( L_t^i \right)^{1+\nu} \right] \right\} \tag{29}$$

subject to labor demand (25). Households which cannot reset wages set their wage via the indexation rule

$$W_t^i = W_{t-1}^i (1+g)\, \pi_{t-1}^{\iota_w} \bar{\pi}^{1-\iota_w}. \tag{30}$$

[11] The model features a shock to liquidity demand in the form of an AR(1) process which lowers safe asset holdings at the expense of consumption, thus distorting the Euler equation. The full set of equations is listed in the Online Appendix.

## 2.7 Monetary policy

The central bank sets nominal interest rates by means of policy rules, where a standard inertial Taylor rule constitutes the benchmark case:

$$R_t = (R_{t-1})^{\rho_r} \left( \left( \frac{\pi_t}{\pi^*} \right)^{\gamma_\pi} \left( \frac{y_t}{y_t^{pot}} \right)^{\gamma_y} R_n \right)^{1-\rho_r} r_t^m, \tag{31}$$

where $R_t$ denotes the nominal interest rate, $\gamma_\pi$ and $\gamma_y$ the weights on inflation and the output gap respectively, $\rho_r$ the Taylor rule persistence parameter and $R^n$ the steady state nominal interest rate.[12] The monetary policy shock $r_t^m$ follows an AR(1) process ($log\left(r_t^m\right) = \rho^m log\left(r_{t-1}^m\right) + \epsilon_t^m$). The policy rule entails a standard output gap measure in line with standard New Keynesian DSGE models, where $y_t$ and $y_t^{pot}$ refer to detrended output and potential output respectively.[13] The central bank may be constrained by the zero lower bound (ZLB) on nominal interest rates.[14]

$$R_t \geq 1. \tag{32}$$

**Alternative monetary policy strategy:**

I study further the role of monetary-fiscal interaction by studying the role of an alternative monetary policy strategy in determining the effect of fiscal policy under output hysteresis. Specifically, I consider price level targeting (PLT).[15] Under PLT monetary policy targets the price level and thus aims at making up for any past under-/ overshooting of inflation by subsequent phases with above (below) target inflation and is modeled in what follows as:

$$R_t = (R_{t-1})^{\rho_r} \left( \left( \frac{\pi_t}{\pi^*} \right)^{\gamma_\pi} \left( \frac{y_t}{y_t^{pot}} \right)^{\gamma_y} \left( \hat{P}_t \right)^{\gamma_P} R_n \right)^{1-\rho_r} r_t^m, \tag{33}$$

[12] Target inflation $\pi^*$ is set to 2% annually. Steady state annualized nominal interest rates equal to 3% annually, matching a long-run real interest rate of 1%, in line with Holston et al. (2017) (see 2.10 for more details on the model calibration).

[13] More precisely, potential refers to the allocation under flexible prices and wages and detrended output is defined as $y_t = \frac{Y_t}{A_t}$.

[14] The occasionally binding constraint is implemented by means of the piecewise-linear method Occbin (Guerrieri and Iacoviello (2015)).

[15] For an in-depth analysis of the performance of make-up strategies under endogenous growth in a low $r*$ environment see Elfsbacka Schmöller and Spitzer (2022).

where $\hat{P}_t$ denotes the deviation from target price level.

## 2.8 Aggregation

The economy is subject to the aggregate resource constraint

$$Y_t = C_t + \left[1 + f_i\left(\frac{I_t}{I_{t-1}}\right)\right] I_t + \left[1 + f_a\left(\frac{I_t^a}{I_{t-1}^a}\right)\right] I_t^a + \left[1 + f_x\left(\frac{X_t}{X_{t-1}}\right)\right] X_t + G_t, \tag{34}$$

which states that final output is consumed, used for physical capital investment, governmnet spending, as well as for expenditure on technology adoption and innovation.[16]

## 2.9 Connection to previous literature

The model assumptions underlying this framework are consistent with the previous literature on New Keynesian DSGE models with endogenous total factor productivity dynamics through productivity-enhancing investment. This class of frameworks generally models technology growth as a process in two margins, where the first describes the progress in the technology frontier and the second the diffusion of technologies to production. The most commonly used approach in the literature is to combine the Comin and Gertler (2006) endogenous TFP mechanism with otherwise standard New Keynesian DSGE model features (see in particular Moran and Queralto (2018), Anzoategui et al. (2019) and Ikeda and Kurozumi (2019)). Trend growth in these frameworks is thus determined by investment of innovators in R&D and by investment in technology adoption.

As to the New Keynesian model backbone and the technical specification of the R&D and technology adoption process, this model builds most strongly on the framework by Moran and Queralto (2018).[17] Differently to their model, I directly impose the nonlinearity of the zero lower bound. Further, and differently to the previous literature more broadly, I study fiscal

[16]This section presented the central equilbrium conditions. The remaining conditions characterizing the equilibrium are listed in the online appendix.

[17]Moran and Queralto (2018) develop this framework study the long-run effects of monetary policy on TFP and the long-run trend as well as the permanent output costs under constrained monetary policy at the ZLB.

policy and introduce growth policies in the form of direct fiscal support to R&D and technology adoption as novel short-run stabilization tools in the DSGE context and study fiscal multipliers under endogenous trend growth. I further derive the role of monetary-fiscal interaction in this context. Specifically, I model alternative monetary policy strategies, in particular in the form of make-up strategies (PLT), to show the dependence of fiscal multipliers on the respective underlying monetary policy strategy. I further study different type of scarring mechanisms in demand- and supply-driven recessions and the respective implications for inflation dynamics and design of fiscal policy. I further study the role of various fiscal policy tools in alleviating scarring at and accelerating liftoff from the ZLB.

## 2.10 Parameterization

This section presents the parameterization of the structural model parameters based on Moran and Queralto (2018).[18]

**Preferences and production:** The discount factor is set to generate in conjuncture with the rate of TFP growth on the balanced growth path a real interest rate of 1%.[19] TFP growth on the balanced growth path is set to the average annualized US TFP growth post-2005 of 0.5. Habit persistence $h$ and the inverse Frisch elasticity are respectively set to 0.5. The capital share corresponds to 0.33 and the rate of capital depreciation to 0.025. $\vartheta$, the final output elasticity with respect intermediate goods, is set to generate purely labor-augmenting growth.[20] Lastly, the adjustment cost parameter of physical capital $f_k''$ equal to 5.5. Steady state employment is normalized to unity.

**Prices, wages and monetary policy:** The Calvo price and wage setting parameters $\theta_p$ and $\theta_w$ are set to 0.93 and 0.9 respectively. Price and wage indexation equal to 0.5 respectively.[21]

[18]More precisely, if not stated otherwise the model is calibrated as in Moran and Queralto (2018), adjusted for quarterly frequency.

[19]This value is set to match the average $r^*$ estimates by Holston et al. (2017) since the Great Recession

[20]Technically, we set $(1-\alpha)(\vartheta-1)=1$ which allows for a simplified representation of the balanced growth path. Note that the corresponding markup for intermediate goods ( $\vartheta/(\vartheta-1)=1.67$) is in line with the choice (1.6) in Comin and Gertler (2006).

[21]Note that estimated price and wage rigidities in this models class typically range above the parameters underlying DSGE models with exogenous technology. The estimation results are in line with more recent studies on nominal rigidities (see, for instance Del Negro et al. (2015)).

The elasticity of substitution across final goods producers and across labor types are respectively set to 6, generating steady state markups of 20%. The inflation target is set to 0.5% quarterly. Monetary policy is set by means of interest rules, which in the baseline model corresponds to an inertial Taylor rule, with persistence parameter 0.8 and inflation and output weights of 1.5 and 1 respectively.

**Research and development and technology adoption:** The obsolescence rate of technologies $1-\phi$ is set to 0.025, generating an obsolescence rate consistent with the empirical estimates in Bosworth (1978) and Caballero and Jaffe (1993). The elasticity of adoption is set to 0.925.[22] The steady state adoption rate is set to 0.05, generating an average average technology adoption lag of five years, matching adoption lags of new technologies in the data.[23] The elasticity of R&D elasticity equals to 0.30 and the strength of the spillover from R&D to technology adoption to 0.29[24] Lastly, the parameters governing the adjustment costs for R&D and adoption are set to 6 respectively, reflecting the relatively lower empirical volatility of research and development versus capital investment.[25] The disutility of labor $\psi$, R&D efficiency $\chi$ and the adoption process constant $\kappa_\lambda$ are set to replicate the targeted rate of TFP growth on the balanced growth path.

[22]This value for the adoption rate set in Moran and Queralto (2018) and was initially derived based on panel data estimates on the proclicality of technology adoption by Anzoategui et al. (2019).

[23]The parameterization of the balanced growth path lag of adoption is thus also consistent with Comin and Gertler (2006), reflecting empirically observable adoption lags.

[24]Moran and Queralto (2018) estimates the research and development parameters empirically.

[25]Moran and Queralto (2018) set adjustment costs to R&D and technology adoption to prevent too volatile technology-enhancing investment in the model compared with the data. Due to the absence of aggregate technology adoption series $f''_{R\&D} = f''_{ta}$ is assumed due to the similarity of this class of investment.

| Parameter | Description | Value |
|---|---|---|
| $\alpha$ | Capital share | 0.33 |
| $\beta$ | Discount factor | 0.9994 |
| $h$ | Habit persistence | 0.5 |
| $\nu$ | Inverse Frisch elasticity | 0.50 |
| $\delta$ | Capital depreciation | 0.025 |
| $f_k^{''}$ | Capital adjustment costs | 5.5 |
| $\bar{L}$ | Steady state employment | 1 |
| $\theta_p$ | Calvo prices | 0.93 |
| $\theta_w$ | Calvo wages | 0.9 |
| $\iota_p$ | Price indexation | 0.5 |
| $\iota_w$ | Wage indexation | 0.5 |
| $\mu$ | Elasticity of substitution (final goods) | 6 |
| $\omega$ | Elasticity of substitution (labor) | 6 |
| $\gamma_\pi$ | Inflation weight | 1.5 |
| $\gamma_y$ | Output weight | 1 |
| $\rho_r$ | Persistence (policy rule) | 0.8 |
| $\pi^*$ | Inflation target (quarterly) | 0.005 |
| $\vartheta$ | Elasticity of substitution (intermediates) | 2.493 |
| $\zeta$ | R&D elasticity | 0.304 |
| $\rho^\lambda$ | Adoption elasticity | 0.925 |
| $\bar{\lambda}$ | Steady state adoption rate | 0.05 |
| $\eta$ | R&D-adoption spillover | 0.294 |
| $1-\phi$ | Obsolescence rate | 0.025 |
| $f_{R\&D}^{''}$ | Adjustment costs R&D | 6 |
| $f_{ta}^{''}$ | Adjustment costs adoption | 6 |
| $100 * \left(g^{\frac{1}{\vartheta-1}}\right)$ | TFP growth (steady state) | 0.5 |

Table 1: Model calibration

# 3. Fiscal policy under endogenous growth

This section studies the role of government spending (section 3.1) as well as growth policies novel in the DSGE setup in the form of fiscal support to R&D (section 3.2.1) and technology adoption (section 3.2.2). Section 3.3 derives the respective fiscal multipliers over the short and long run.

## 3.1 Government spending

This section analyses the effect of government spending which evolves according to the following AR(1)-process:

$$log(G_t) = (1 - \rho^g)\, G_{ss} + \rho^g log(G_{t-1}) + \epsilon_t^G, \tag{35}$$

where $\rho^g$ denotes the shock persistence ($\rho^g \in [0, 1]$) and $G_{ss}$ equals to government spending on the balanced growth path. The latter is set to match a government spending to GDP ratio in the steady state of 0.2. Government spending is financed through lump sum taxation on households ($G_t = T_t$).

Figure 2 shows the macroeconomic dynamics in response to an expansionary government spending shock. An expansion in government spending crowds out consumption and investment in physical capital. Under the endogenous TFP mechanism there is an additional channel which operates through productivity-enhancing investment as government spending crowds out in addition also investment in research and development and in technology adoption. Due to this *long-run crowding out*, government spending generates a drop in TFP and thus the long-run trend subject to permanent output losses.

## 3.2 Fiscal growth policies

Since the framework models total factor productivity dynamics endogenously it gives the possibility to directly study growth-promoting fiscal policy in the form of support to technology-enhancing investment. This type of fiscal policy is the main focus of this section. Given the

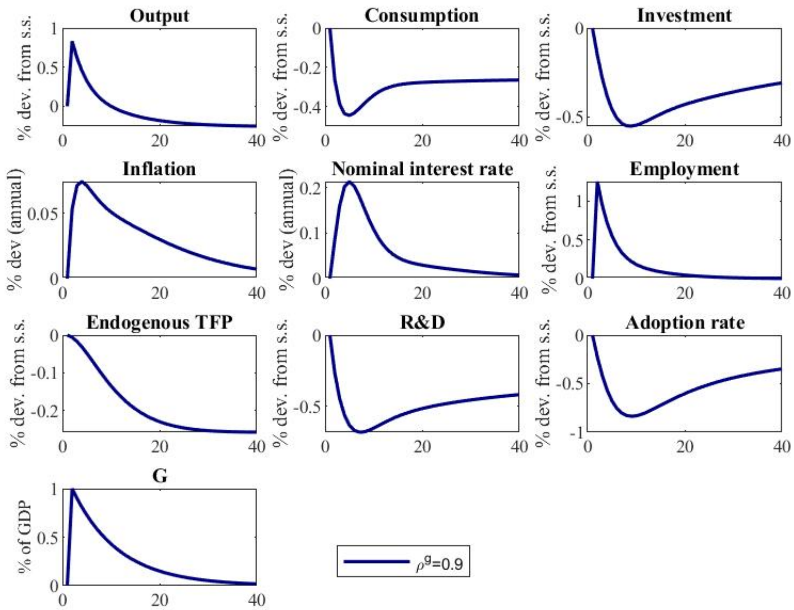


Figure 2: Macroeconomic response to a government spending shock (1% of GDP (pre-shock))

two-stage technology process, two main types of growth promoting policies are considered, specifically fiscal support to R&D (section 3.2.1 ) and policies promoting technology adoption on the firm-level (3.2.2). While growth-promoting policies are at the focus of the endogenous growth literature focusing on long-run growth, this analysis specifically considers their effect not only with respect to the evolution of long-run aggregate supply but also as a short-run stabilization tool novel to the DSGE context.

#### 3.2.1 Fiscal support to R&D

This section fiscal growth policies target to research and development. Specifically, I assume that the government finances a fraction $s_{R\&D}$ of entrepreneurs' research and development investment. The fiscal support to R&D is financed by means of lump sum taxation on households.

The fiscal support to R&D raises the optimal investment in R&D for a given state of the economy and related value of an unadopted technology $J_t$. Technically, I assume $s_{R\&D}$ follows an AR(1) process

$$log(s_t^{R\&D}) = \rho^{s_{R\&D}} log(s_{t-1}^{R\&D}) + \epsilon_t^{s_{R\&D}}, \tag{36}$$

where $\rho^{s_{R\&D}}$ denotes the persistence of the shock ($\rho^{s_{R\&D}} \in [0, 1]$). The inherent assumption is also that the fiscal support is non-divertible, meaning that firms cannot use them for other purposes than for research and development.

Figure 3 (blue line) illustrates the effect of growth-promoting fiscal policies to R&D.[26] The

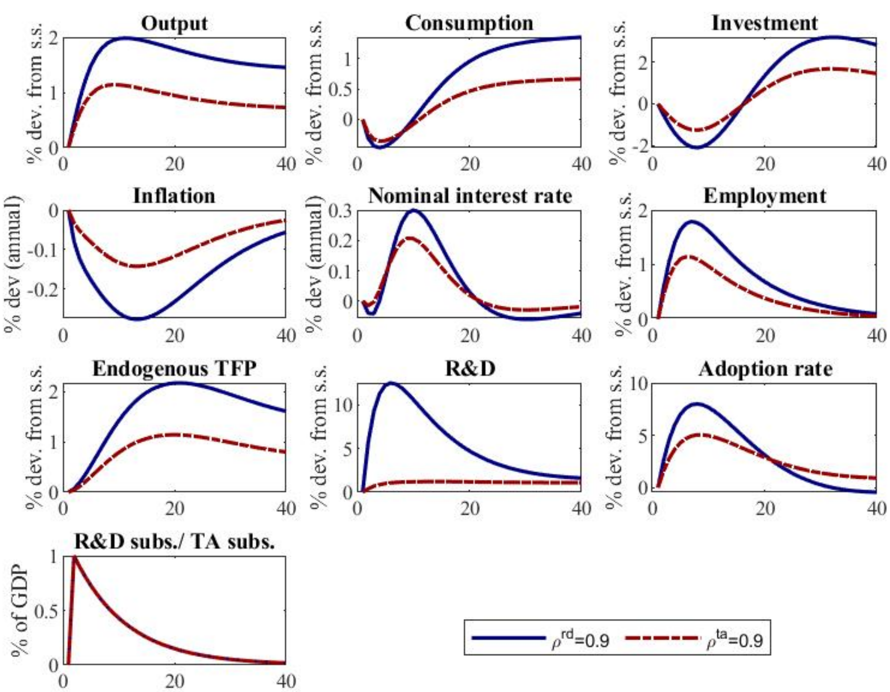


Figure 3: Macroeconomic response to fiscal growth policies to R&D (blue line) and technology adoption (red line) (1% of GDP (pre-shock)).

fiscal support to R&D raises aggregate demand and thus aggregate output. Consumption and capital investment experience transitory crowding out and employment expands. Importantly, the fiscal support generates a substantial increase in research and development investment. In

[26] The shock size corresponds to 1% of pre-shock GDP.

addition, there is a second round effect to technology adoption which operates through the complementarity of the innovation and adoption process, thus generating also an increase in technology adoption activity. As a result, total factor productivity increases substantially, leading to permanent output gains and counteracting potential scarring effects in crisis times. Inflation initially increases and subsequently decelerates as gains in total productivity decreases firms' marginal costs sufficiently strongly to offset inflationary pressures. After the initial decline, consumption and capital investment revert and adjust to the permanently higher level.

Fiscal support to R&D thus boost aggregate demand, while simultaneously generating a pronounced expansion in TFP and the long-term output path. With respect to timing, it is important to note that research and development is a slowly moving process, i.e. the peak impact on the generation of new technologies is reached only over the medium-term and is thus realized with a lag. Fiscal support to research and development can be considered very effective in raising the technology stock by expanding the entire technology frontier and hence simultaneously the possibilities for future technology adoption.

#### 3.2.2 Fiscal support to technology adoption

Another option for implementing growth-promoting fiscal policy is fiscal support to technology adoption. I model technology adoption fiscal policies as a share $s_t^{TA}$ of overall expenses on technology adoption which follows an AR(1)-process:

$$log(s_t^{TA}) = \rho^{s_{TA}} log(s_{t-1}^{TA}) + \epsilon_t^{s_{TA}}, \tag{37}$$

where $\rho^{s_{TA}}$ denotes the persistence of the shock ($\rho^{s_{TA}} \in [0, 1]$). The fiscal support is paid by the government to the adoption sector and financed by lump sum taxes on households.

This highlights that for any specific gain from adopting a technology, the investment in technology adoption will increase, owed to the diminished costs of adoption under the fiscal growth policy. Via this channel, fiscal policy can directly raise technology adoption in a downturn, thus alleviating the related scarring effects. Figure 3 (red line) illustrates the effect of fiscal support to technology adoption on the macroeconomy. We observe that a temporary support to firms' technology adoption boosts aggregate demand instantaneously, discernible from an increase in output. Employment increases, consumption and physical capital investment experience initial crowding out. Importantly with respect to the evolution of the trend component, fiscal support to technology adoption increases the efforts undertaken to incorporate new technologies in production, thus also reaping productivity gains from delayed diffusion. The corresponding positive effect on total factor productivity induces permanent output gains. The boost to total factor productivity reduces firms' marginal costs, inducing a deceleration in inflation.

### 3.2.3 Growth policy mix

Growth policies in this model can be implemented by means of fiscal support to the R&D sector, to technology adoption efforts by firms or to both. Supporting technology adoption is subject to the advantage of raising TFP growth rapidly by fostering technology diffusion. Fiscal policy support to R&D, in turn, has the benefit of raising the technological frontier and of boosting the potential for all future technology adoption possibilities. While this may hold substantial productivity gains in store, the latter are realized with a relatively longer lag as research and development constitutes a slowly-moving process. In sum, my results suggest that a combination of fiscal support to both research and development and technology adoption activities exploits the productivity gains on both margins, rendering a growth policy mix desirable from the perspective of the model.

## 3.3 Fiscal multipliers under endogenous growth

This section quantifies fiscal multipliers. Table 2 presents the impact multipliers, the cumulative multipliers over various horizons (4, 8, 16 quarters) and the respective peak cumulative multipliers.[27] Further, I introduce the concept of a *trend multiplier* to quantify the permanent, long-run trend effects of fiscal policy. It measures the magnitude of the permanent level shift

[27]Cumulative multipliers are defined as the cumulative increase in output divided by the cumulative increase in fiscal spending.

| | Impact multiplier | 1 year | 2 years | 4 years | Peak | Trend multiplier |
|---|---|---|---|---|---|---|
| **G** | 0.83 | 0.67 | 0.54 | 0.46 | 0.83 (1q.) | -0.26% |
| **R&D** | 0.46 | 0.99 | 1.32 | 1.15 | 1.35(10q.) | +1.42% |
| **Techn. adopt.** | 0.35 | 0.69 | 0.87 | 0.75 | 0.88(9q.) | +0.69% |

Table 2: Fiscal multipliers under endogenous growth

*Multipliers to expansionary fiscal policy shocks equal to 1% of GDP (pre-shock) and alternative shock persistences; 1,2 and 4th year multipliers denote cumulative multipliers; peak multipliers defined as the maximum cumulative multiplier; trend multipliers capture the permanent output effect, i.e. the percentage change in the long-run trend component ($A_t$).*

in TFP, defined in percentage changes relative to the initial trend path. More concretely, the trend multiplier states that the respective fiscal policy is associated with a permanent shift in the technology stock of x% relatively to its pre-shock trend level.

The fiscal multipliers under the benchmark scenario are computed for fiscal expansions equal to 1% of GDP with a persistence of $\rho = 0.9$. We observe that government spending is subject to the highest impact multiplier (0.83), while on impact the multipliers of fiscal R&D and technology adoption policies range relatively lower (0.46 and 0.35), reflecting the differential timely dynamics of fiscal growth policies. The peak government spending multiplier is reached instantaneously on impact while growth-promoting policies are relatively more slow-moving since their effect builds up only gradually over time, reaching peak cumulative multipliers after ten (R&D) and nine quarters (technology adoption).

We further observe that fiscal multipliers of fiscal growth policies can be sizeable and generally range significantly above the respective multipliers of government spending. While this holds true for fiscal support to technology adoption which generates a peak multiplier of 0.88, multipliers of fiscal R&D policies are particularly pronounced. This applies as support to research and development directly targets the technological frontier and hence also raises the possibilities for future technology adoption. Cumulative multipliers of R&D fiscal policies rise well above one and are characterized by a peak multiplier of 1.35.

Under exogenous technology fiscal policy has only transitory effects and does not impact the long-run trend, which results in a trend multiplier of zero. By contrast, and as discussed in sections 3.1 and 3.2, the effects of fiscal policy are permanent under endogenous growth, resulting in non-zero trend multipliers with signs varying with the respective fiscal policy tool. An exogenous increase in government spending generates only a transitory, i.e. short-run boost to aggregate output but is subject to long-run crowding out as over time technology-enhancing investment in R&D and technology adoption are crowded out, thus weighing on the long-run trend in a permanent manner. This mechanism results in a negative trend multiplier of -0.26% in the baseline scenario. By contrast, fiscal growth policies result in a permanent increase in the technology stock and the long-run trend and are hence subject to positive trend multipliers of 0.69% for technology adoption and 1.42% for R&D policies respectively. Note that the permanent shift in TFP as measured by the trend multiplier enters the trajectory of aggregate output additively, resulting in substantial cumulative differences in aggregate output and income over time.

#### Discussion

I briefly discuss the role of the modeling assumptions underlying the results on fiscal policy presented in section 3. In this paper, government spending is wasteful as it does not generate direct utility for the household. Departing from this standard assumption would, as also in standard models with exogenous technology, affect government spending multipliers. I further focus on the standard assumption of the lump-sum taxation benchmark. Under distortionary taxation, for instance on income from labor or capital, fiscal multipliers would also be influenced by the second round effects operating through taxation and thus generally differ from the baseline with lump sum taxes. Lastly, the results are derived in the standard, representative agent setup as the focus of this paper is to depart only with respect to endogenous technology growth dynamics from the standard DSGE benchmark to isolate the effect of the endogenous TFP mechanism. Departing from the representative agent setting and, for instance deriving a model with heterogeneous agents and endogenous technology dynamics, would constitute a promising avenue for future research. This approach would permit the study of distributional effects and its implications for the size of fiscal multipliers.

# 4. Scarring mechanisms

In this framework, scarring effects, i.e. permanent harm to aggregate output can occur endogenously. Specifically, and differently to standard New Keynesian models, the technology stock and thus the long-run trend are no longer strictly exogenous but modeled endogenously in general equilibrium and the cycle and the trend are interlinked. I show next different type of scarring mechanisms from the perspective of the model, with a special focus on the role of the choice of fiscal tool in counteracting hysteresis effects and on the related inflation implications. Figure 4 shows the macroeconomic dynamics in a demand-driven recession, as induced by a liquidity demand shock, as well as a recession generated by a technology shock as an example of a supply-driven recession.[28]

**Demand-driven recession (liquidity demand shock):** Under the demand-driven recession scenario (blue line), consumption, investment in physical capital, employment and aggregate output fall. Inflation decreases in response to subdued aggregate demand. The aggregate output drop weighs on technology-enhancing investment in R&D and technology adoption, as the contraction lowers firm profits (equ. 19) and thus the values of an unadopted technology (equ. 8) and an adopted technology (equ. 7) respectively, resulting in a slowdown of investment along both margins of technology growth. The depressing effect on TFP and hence the long-run trend amplifies the recession. The deceleration in TFP generates permanent scars to aggregate output as TFP does not revert to its initial trend path, hence causing a level shift in the long-run trend an aggregate output path.

**Supply-driven recession (technology shock):** In the supply-driven recesssion scenario, induced by a contractionary technology shock[29] (red line), output, consumption and capital

[28] Figure 4 pursues the main goal of showing macroeconomic dynamics and scarring effects in response to a shock to liquidity demand and a technology shock respectively. Shocks are set to generate a peak-to-trough output drop of 1% under both recession scenarios for the purpose of comparability.

[29] Technically, the supply-driven recession is generated by means of a technology shock, i.e. to the technology

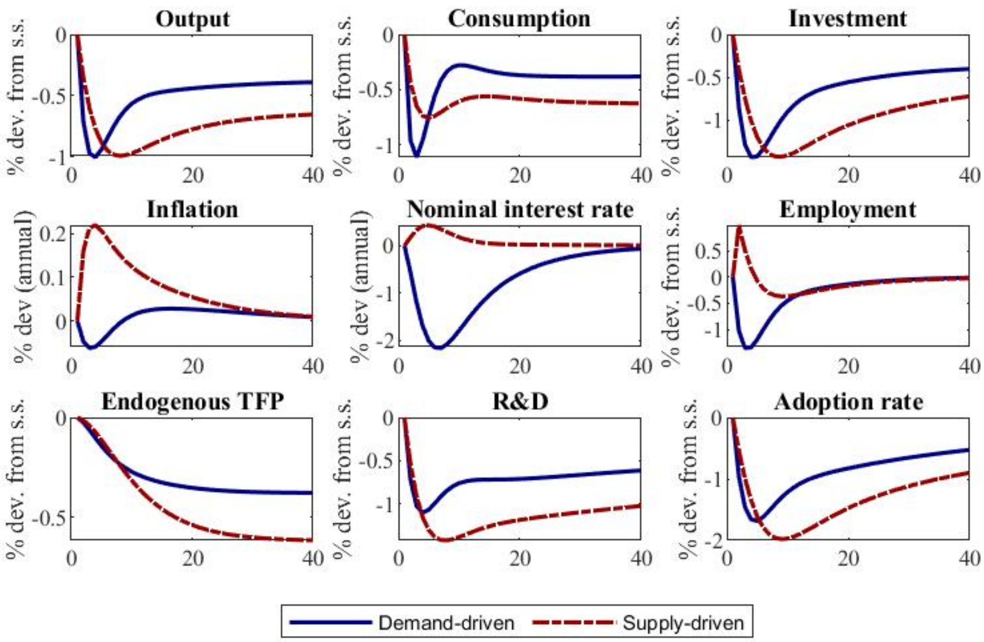


Figure 4: Scarring mechanisms in demand- and supply-driven recessions

investment fall. Inflation increases as the negative technology shock raises inflationary pressures through marginal costs. Firm profits decline in the context of the contraction (19), lowering the incentive to invest in R&D (equ. 8) and technology adoption investment (equ. 7), resulting in a deceleration in technology-enhancing investment. The latter translates into a slowdown in total factor productivity with permanent scarring effects to the long-run trend and aggregate output path.

**Inflation response and choice of fiscal tool:** This section showed that both demand- and supply-driven recessions can be subject to pronounced scarring effects. The prevention of long-run scars to aggregate output can thus also constitute a motive for expansionary fiscal policy intervention in recessions. As analyzed in detail in section 3.1, government spending generates only a transitory, i.e. short-run expansion in aggregate output, while weighing on TFP and the long-run trend through long-run crowding out effects. The attempt to counteract scarring by

of intermediate goods producers $\theta_t$.

means of government spending would thus instead further reinforce the hysteresis effects. Fiscal growth policies which directly target R&D and technology adoption, in turn, directly promote technology-enhancing investment and TFP growth (section 2.2) and can thus be effective in alleviating recession-induced hysteresis effects.

As a central difference between the demand- and supply-driven recession scenarios emerge the inflation response since the former is characterized by a fall and the latter by an increase in inflation respectively. Preventing scarring in supply-driven recessions may thus be particularly challenging because output and inflation are pushed in opposite directions. Fiscal growth policies overcome this challenge prevalent in supply-driven recessions given their direct support to productivity-enhancing investment which is effective in counteracting the long-run scars on the trend margin, while their disinflationary effect simultaneously counteracts the inflationary pressure in supply-driven recessions and hence fosters the realignment of inflation with target. This observation thus highlights a further advantage of fiscal growth policies, specifically their implementability in not only recessions in which output and inflation move in the same direction (demand-driven case) but also in recessions in which a trade-off between inflation and output stabilization occurs (supply-driven case).

# 5. Monetary-fiscal interaction

Monetary policy is long-run non-neutral under endogenous growth as monetary stimulus influences technology-enhancing investment and thus the long-run aggregate output path.[30] Hence, while the response of fiscal policy also more generally depends on the response of monetary policy, the role of monetary-fiscal interaction is particularly important under endogenous growth. This section studies the role of monetary-fiscal interaction under endogenous growth. I focus on two central aspects of short-run monetary-fiscal interaction: on the role of the underlying monetary policy strategy for fiscal multipliers (section 5.1) and on the role of fiscal policy tools in reducing the long-run scars of ZLB episodes and in accelerating lift-off (section 5.2).

[30] See Elfsbacka Schmöller and Spitzer (2022) for a detailed analysis of the role of long-run money non-neutrality and the conduct and operating environment of monetary policy under endogenous growth.

## 5.1 Monetary policy strategies and fiscal policy

Due to long-run non-neutrality of monetary policy under the endogenous growth mechanism, the effect of fiscal policy over the short and long run, however, crucially also depends on the response and mechanisms underlying monetary policy. The results presented in the previous sections are based on a standard Taylor rule under which nominal interest rates are set based on inflation and a standard output gap measure. In what follows, I study the role of the underlying monetary policy strategy. Specifically, I study the role of an inflation-based make-up strategy, as recently adopted by some advanced economy central banks, under which bygones in terms of misses as to inflation stabilization are no longer bygones, by example of price level targeting (PLT). Instead, the central bank commits to stabilize the price level[31] and thus to make up for any past over or undershooting of inflation.

Figure 5 shows the difference in the impulse responses under PLT and the baseline Taylor rule for the respective fiscal tools[32] and demonstrates that the underlying monetary policy strategy is key for the effect of fiscal policy. Regarding government spending, we observe the following key properties. Firstly, the raised inflationary pressure following expansionary government spending implies under PLT and the inherent commitment to offset the upward deviation in the price level a subsequent relative tightening of monetary policy to realign the price level with the target path. As a result, PLT is subject to a further intensification of long-run crowding out of government spending and the intensification of scarring with respect to the long-run trend (green line).

Regarding the response to expansionary growth-enhancing fiscal policies to R&D (blue line) and technology adoption (red line) under PLT relatively to inflation targeting we observe the following. Since both policies are disinflationary and thus exert downward pressures on the price level. As the central bank aims to restore the price level, fiscal growth policies to R&D and technology adoption are accompanied by a relatively more accommodative monetary policy stance. The latter further amplifies the expansionary effect on aggregate output and technology-enhancing investment and thus on the long-run trend path.

[31] In the simulations, the targeted price level path is based on an underlying inflation target of 2% annually.

[32] Technically, Figure 5 shows: $\text{Response}_{\text{PLT}} - \text{Response}_{\text{TR}}$ in units expressed as stated on the respective axes.

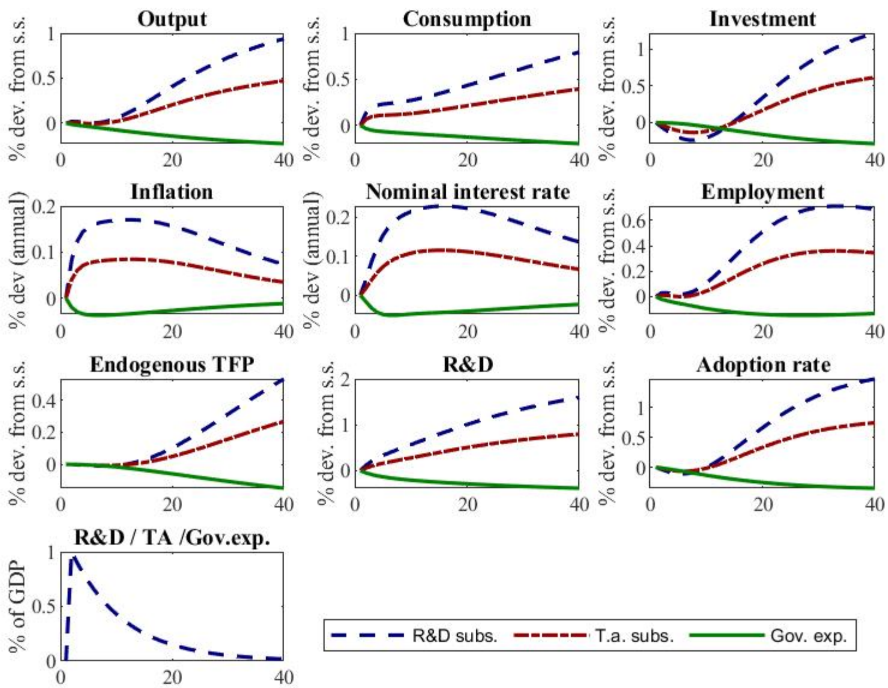


Figure 5: Comparison of fiscal policies under PLT relative to baseline Taylor rule

*Differences in the impulse responses under PLT relative to the baseline Taylor rule, expressed as differences in the impulse responses of the respective policies between the simulations under PLT and benchmark Taylor rule (units as indicated on the respective axes); shock sizes and persistences as specified in section 3.*

In sum, under an inflation-based make-up strategy as implied by PLT, the results established in section 3 are further intensified as the extent of long-run crowding out under government spending is further amplified, while extra stimulus is provided in response to growth-promoting fiscal policies. This result also further shows the amplified role of monetary-fiscal interaction under endogenous growth as the underlying monetary policy strategy is crucial in determining not only the short- to medium-term response to fiscal stimulus but in addition also as to the technology stock and hence the degree of cycle-trend interaction.

## 5.2 Long-run scars and lift-off from the ZLB

The depth of recessions and the extent of hysteresis effects are particularly pronounced at the ZLB due to the amplification of the spillovers from weak aggregate demand to long-run aggregate supply when monetary policy is constrained (see Appendix A.1 for a more detailed discussion of the underlying mechanisms.). Figure 6 shows the model dynamics at the ZLB in the absence of fiscal support (blue line) and under expansionary fiscal support to R&D.[33] We observe that the fiscal support to R&D generate a pronounced expansion of the investment in research and development and, with a lag, in technology adoption.[34] The expansion in technology-enhancing investment generates a boost to TFP which counteracts the scarring effects of the ZLB episode prevalent in the absence of the policy intervention and thus supports the stabilization of the long-run trend. The temporary boost to R&D reinforces the disinflationary dynamics prevalent at the ZLB as the expansion in TFP exerts additional downward pressure on marginal costs and thus further reinforces the shortfall in inflation in ZLB episodes.

Regarding the effect on lift-off from the ZLB the output and inflation response respectively work in opposite directions. The expansionary output effect outweighs the disinflationary impact on inflation, resulting in a reduced length of the ZLB episode, albeit to a lesser extent than suggested by the extent of the output boost. Growth-promoting fiscal policies targeted to R&D thus constitute effective tools in accelerating recoveries from ZLB episodes, while to some extent also supporting the return of interest rates to steady state levels.

Comparing the findings for R&D policies with the role of government spending at the ZLB (see section A.2) shows the following. Firstly, while the degree of long-run crowding out is somewhat less pronounced at the ZLB due to the lack of a counteracting response to the fiscal expansion under constrained monetary policy, long-run crowding out of government spending

[33] Technically, the fiscal growth policy to R&D is implemented one period after the ZLB-inducing shock, with a magnitude of the fiscal stimulus equal to 1% of pre-shock GDP and a shock persistence of 0.9 (see also lower left panel).I focus on R&D when studying the effect of growth-promoting policies at the ZLB for tractability. Note that the effect and mechanisms of fiscal policy targeted at technology adoption at the ZLB is highly similar. The key differences constitute a less expansionary effect on aggregate output and TFP and hence a to some extent less pronounced reduction in the extent of scarring at the ZLB, while at the same time exerting a less disinflationary effect.

[34] The expansion of the set of unadopted technologies translates over time into an increase in the number of successfully adopted technologies.

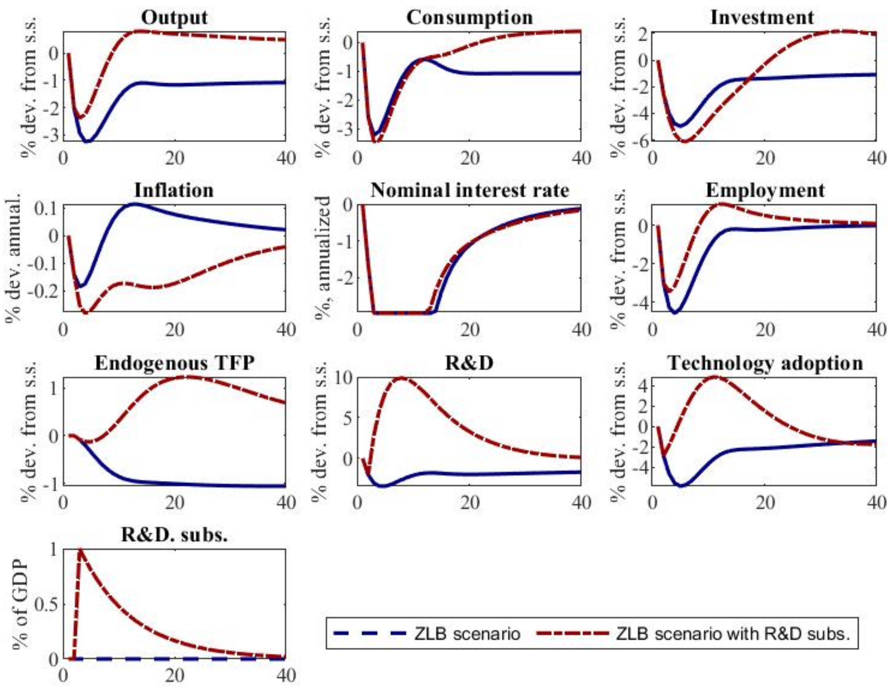


Figure 6: ZLB scenario without fiscal stimulus (blue line) and with fiscal support to R&D (red line).

*ZLB scenario induced by means of a large contractionary liquidity demand shock which causes the ZLB to bind in the absence of further policy interventions; fiscal support to R&D implemented in the period following the ZLB-inducing shock equal to 1% of pre-shock GDP (shock persistence $\rho_{RD} = 0.9$).*

is observable also at the ZLB. Thus, while government spending supports inflation and boosts output over the short run at the ZLB, the counteracting effect on TFP exerts a further depressing effect on the output trajectory over time, thus intensifying the scarring effects of ZLB episodes.

# 6. Conclusion

Previous evidence on fiscal policy is based on frameworks with exogenous trend. This paper departs from this simplifying assumption and studies fiscal policy in a New Keynesian model in which technology growth and the long-run trend are modeled in general equilibrium. In this setting, hysteresis effects can occur endogenously due to cycle-trend interaction. I show that demand- as well as supply-driven recessions can result in pronounced long-run scars and thus permanent output losses.

A key result of this paper is that fiscal policy has long-run effects under endogenous growth. Moreover, the type of fiscal stimulus determines the sign and magnitude of fiscal multipliers. Government spending leads to *long-run crowding out* as it crowds out investment in R&D and technology adoption and thus lowers the trend path. I introduce fiscal growth policies as novel stabilization tools in the DSGE context under which fiscal policy targets R&D and technology adoption investment and thus simultaneously boosts aggregate demand and expands technology-enhancing investment and the long-run trend. Quantitatively, the government spending multiplier peaks on impact and is over time reduced by long-run crowding out and adverse trend effects. The trend multiplier, which measures the policy-induced long-run output shifts, is negative (-0.3%). Fiscal growth policies can generate sizeable multipliers, in particular when targeted to R&D, which realizes cumulative multipliers distinctly above unity. Trend multipliers are positive with upward trend shifts of +0.7% for technology adoption and +1.4% for R&D. These results highlight the pronounced aggregate output effects and the increased role and scope of fiscal policy under endogenous growth.

The importance of monetary-fiscal interaction is amplified due to the long-run non-neutrality of monetary policy. The underlying monetary policy strategy is a key determinant fiscal multipliers: make-up strategies lower long-run crowding out of government spending but raise multipliers of fiscal growth policies relatively to the inflation targeting benchmark. Further, growth-enhancing fiscal policies alleviate permanent scars from the ZLB when monetary policy is constrained. Growth policies are disinflationary and are thus suitable stabilization tools also in supply-driven recessions when monetary policy faces a trade-off between output and inflation stabilization.

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# A. Appendix

## A.1 ZLB dynamics and scarring

Figure 7 shows the macroeconomic dynamics in response to a large liquidity demand shock in a non-linear model with a ZLB constraint (blue line) relatively to a fully linear model which abstracts from the zero lower bound (red line). A binding ZLB further intensifies the magnitude of the recession due to constraints to monetary policy in economic stabilization, which amplifies the procyclical drop in TFP. As a result, the ZLB constraint amplifies the scarring effects of recessions and the corresponding long-run output losses and is thus subject to long-term costs under endogenous technology growth.

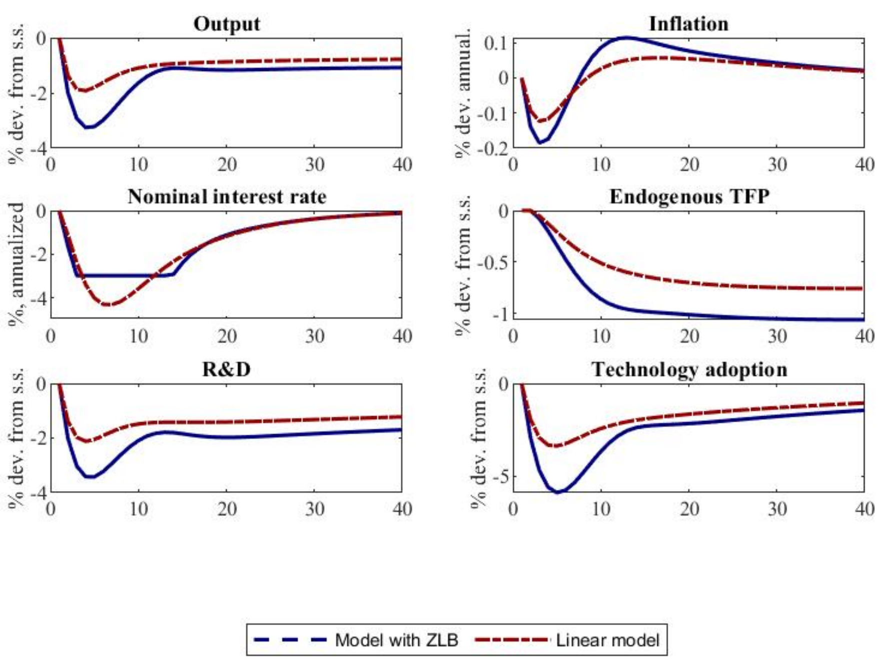


Figure 7: Scarring effects at the ZLB

## A.2 Government spending at the ZLB

Figure 8 shows in more detail the dynamics of expansionary government spending when monetary policy is constrained by the ZLB. As in Figure 6, dynamics at the ZLB are shown in the absence of fiscal policy intervention (blue line) and are confronted by the same scenario with expansionary fiscal policy, in this case in the form of expansionary government spending (red line).[35]

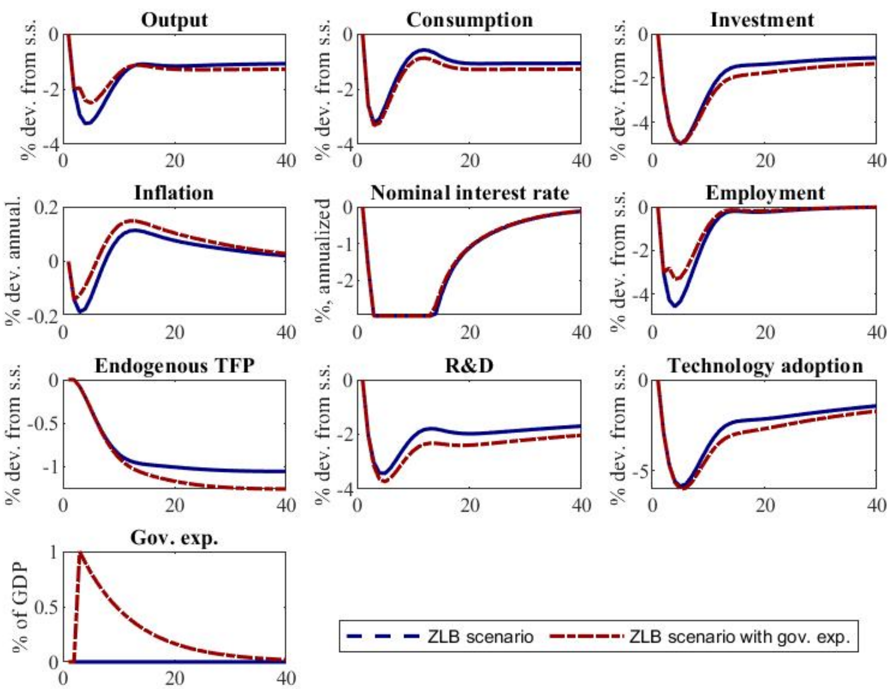


Figure 8: Effect of government spending at ZLB

Expansionary government spending generates a temporary output boost and supports inflation at the ZLB. While overall the degree of long-run crowding out is reduced at the ZLB since the fiscal expansion is not - as typically the case - met by a simultaneous increase in interest

[35]Figure 6 and 8 confront identical ZLB scenarios (blue line) with fiscal interventions of identical persistence and size.

rates,[36] government spending crowds out technology-enhancing investment also at the ZLB. This translates into a deceleration in TFP and thus aggregate output over time. Regarding the extent of scarring, government spending thus only provides stimulus to aggregate output over short horizons, while it over time reinforces the long-run scarring effects of ZLB episodes. Lastly, despite the boost to inflation, expansionary government spending does not significantly accelerate liftoff from the constraint due to the counteracting effects from TFP.

[36]Technically, reduced long-run crowding out of government spending at the ZLB can be shown by comparing the effect of otherwise identical specifications for fiscal stimulus in normal times on the one hand with the difference in the long-run trend component at the ZLB with and without fiscal policy. The result is that otherwise identical specifications of fiscal stimulus lead to relatively less pronounced long-run crowding out at the ZLB than under unconstrained monetary policy.

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