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Original Article

Measuring the macroeconomic responses to public investment in innovation: evidence from OECD countries

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The paper aims to assess the macroeconomic impacts of government investment in Research and Development (R&D) and more generic fiscal policies by quantifying the Gross domestic product (GDP) and business R&D investment multipliers. Following the recent literature on fiscal policy, we combine the Local Projection approach with fiscal shocks estimated using Structural Vector Autoregressive modeling by focusing on a panel of 15 Organization for Economic Co-operation and Development (OECD) countries for the 1981–2017 period. Our findings support the idea that expansionary fiscal policies can positively and persistently affect the GDP level and crowd in business R&D investment. Additionally, our results show that public investment in R&D generates the largest multiplicative effect both on GDP and business R&D than the one associated with more generic public expenditures, even when fiscal expectations are considered.

JEL classification: C33, E62, O25, O30

1. Introduction

The current stagnation that advanced economies have faced in the last decades and the recent crisis generated by the COVID-19 pandemic have sparked wide interest in the role of discretionary fiscal policies in stimulating GDP and its components. The scholarly based literature on fiscal multipliers has demonstrated that expansionary fiscal policies effectively stimulate economic activity, and the fiscal policy composition matters in determining the impact of the GDP level (Auerbach and Gorodnichenko, 2012; Deleidi *et al.*, 2023). In this respect, the International Monetary Fund (IMF) advocates for a public investment push able to stimulate both short-run economic activity and the long-term structural transformation of an economy (International Monetary Fund [IMF], 2014; International Monetary Fund [IMF], 2020; International Monetary Fund [IMF], 2021). The recent crises have also accelerated the debate on the need for a new industrial policy focused on public investment in Research and Development (R&D) targeted at strategic sectors and areas able to stimulate technological advances and innovation (Archibugi and Filippetti, 2018; Mazzucato and Kattel, 2020; Van Reenen, 2020). Similarly, international institutions and academic scholars have highlighted the need to implement Mission-Oriented Innovation Policies (MOIPs) (Mazzucato, 2018; European Commission, 2018a; Larrue, 2021;

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Mazzucato, 2021), namely public policies able to address "grand contemporary societal challenges" and influence the development of technical progress (Mowery, 2012; Mazzucato, 2016; Fisher *et al.*, 2018). Notwithstanding, the IMF shows that public investment in R&D decreased during the last decades, and it recently recommends that countries invest in public R&D activities to boost productivity and long-term growth (International Monetary Fund [IMF], 2021). Yet, despite part of the literature on innovation recognizes the state's capacity to foster innovation and technological change (Acemoglu *et al.*, 2015, 2016) or the need for government investment to fix market failures (Van Reenen, 2020; 2021), to fully understand the challenge-led role of the public sector it is necessary to go further. Indeed, it becomes fundamental to understand how such direct investments in R&D can create new industrial landscapes and new markets, rather than just fixing market failures, by addressing new needs that did not exist before (Foray *et al.*, 2012; Mazzucato, 2013). Recent contributions have demonstrated that targeted investments in innovation can engender strong impacts at the macroeconomic level by stimulating GDP growth, crowding-in business R&D, and fostering innovation more effectively than more standard fiscal policies (Deleidi and Mazzucato, 2021; Mazzucato and Rodrik, 2023; Moretti *et al.*, 2023).

In addition, while the existing literature on innovation has typically analyzed the dynamics of R&D investment at the microeconomic level, it becomes essential to employ a macroeconomic standpoint to fully capture the technological spillover effects generated by public R&D investment (Aghion and Howitt, 1998; Buyse *et al.*, 2020; Rehman *et al.*, 2020). Yet, despite the increasing attention on public investment in R&D, little to no quantitative assessment exists on the dynamic macroeconomic effects of MOIPs and public investment in innovation (Bloom *et al.*, 2019). When considering the empirical literature on fiscal multipliers, the main contributions focus on assessing the effect of total government expenditure on GDP (Ramey, 2016, 2019), while little to no evidence exists about the macroeconomic impact of public investment oriented at promoting structural change and innovation (Deleidi and Mazzucato, 2021; Ziesemer, 2021). Similarly, when considering the industrial literature studying the effects of public demand policies on private innovation, the macroeconomic research is scant, and the few results provide a not-unanimous picture (David *et al.*, 2000; Becker, 2015).

Based on these premises, the current paper aims to assess the macroeconomic effects produced by government investment in R&D by entering both the vast literature on fiscal multipliers and the one on innovation. By focusing on a panel of 15 OECD countries considered for the 1981–2017 period, we assess and quantify the impact of public R&D investment and generic government spending on GDP and business investment in R&D. Multipliers are computed by employing advanced empirical techniques that combine the Local Projections (LP) approach with Structural Vector Autoregression (SVAR) models (Auerbach and Gorodnichenko, 2017; Ramey and Zubairy, 2018; Deleidi *et al.*, 2023). Our findings show that expansionary fiscal policies generate positive and long-lasting effects on the GDP level and crowd in business investment in R&D. However, when comparing different fiscal policies, our results show that public investment in R&D is associated with a higher multiplicative effect on GDP and business R&D than the one produced by more generic government expenditures. Our results are robust to different model specifications and are confirmed even when fiscal expectations are considered.

The paper proceeds as follows. Section 2 provides a review of the existing literature. Section 3 describes data and methods. Sections 4 and 5 present the main findings and Section 6 concludes.

2. Literature review

Our work combines key insights from two different pieces of literature, namely the industrial economic literature underlying the role of the state in shaping and stimulating innovation and business investment and the literature on fiscal multipliers. This section aims to review the two abovementioned pieces of literature.

Part of the industrial literature acknowledges the role of the public sector in influencing innovation and economic growth. While the emphasis is on the high-spillover content of public R&D investments and their ability to generate a higher value (Bloom *et al.*, 2019; Van Reenen, 2020, 2021), the theoretical perspective advocating for MOIPs goes further. Indeed, the latter emphasizes the relevance of government in determining and directing economic growth through the

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realization of strategic investments across the entire innovation chain and creating new technological opportunities beyond the existing technological paradigm, rather than just fixing market failures (Mowery, 2010; Foray *et al.*, 2012; Mazzucato, 2016; Dosi *et al.*, 2021). MOIPs can be defined as systemic public policies based on strategic investments that *de facto* operate as industrial policies that draw on frontier knowledge to attain specific goals, namely big science deployed to meet big problems (Mazzucato, 2018). These policies are based on direct government investment with a high content of R&D activities that can shape and co-create markets and promote technological change and innovation in the economic system by catalyzing investment and creating the potential for spillover effects across different private actors and sectors (Chang and Andreoni, 2020). As demonstrated in the history of innovation, the public sector has been crucial for basic and applied research (Mazzucato, 2018), and demand-side policies have led to the development and diffusion of new technologies (Mazzucato and Perez, 2015). MOIPs have involved many sectors and actors working together to develop specific technologies aligned with missions defined at the state level. These policies have developed a range of technological and non-technological innovations that have been applied and introduced in various economic sectors. Direct public investment in R&D has generated additionality within the economic system by creating new opportunities and increasing business expectations about where future growth opportunities might lie, thus activating private investment that otherwise would not have been possible (Mazzucato, 2013; Allen and Tandberg, 2021). As a result, they successfully influenced the realization and the diffusion of technical progress. For instance, the Apollo "Man on the Moon" mission required investment and innovation in aerospace and many other sectors (e.g., biology, electronics, communication, medicine, textile, and food), and the technological results of such a program propagated to the whole economic system by leading to the realization of new physical products and a variety of knowledge breakthroughs (European Commission, 2018b). Contemporary missions—needed to solve current challenges and complex societal problems (e.g., climate, aging, and health crises)—would require similar cross-sectoral collaborations and systemic transformation across different sectors and actors (Mazzucato, 2018).

On the empirical ground, several works recognize the role of demand management policies in fostering innovation (see, among others, Acemoglu and Linn, 2004; García-Quevedo *et al.*, 2017).[1] A growing empirical literature has analyzed the impact of alternative demand-side innovation policies on private innovative activity. These works have mainly used microdata, while a little part has assessed the effect of those policies at the macroeconomic level (Buyse *et al.*, 2020; Rehman *et al.*, 2020). Additionally, while part of the literature focuses on the role played by public procurement, little evidence has been provided to assess more directed innovation policies. This literature provides a not unanimous picture regarding the crowding in or out effects of public policies on private innovation activities (David *et al.*, 2000; Becker, 2015).[2]

Some studies emphasize the presence of complementarity between private innovation activities and demand-side innovation policies, concluding in favor of a crowding-in effect. For instance, Diamond (1999) uses National Science Board (NSF) aggregate data for the 1953–1995 period to examine the impact of federal spending on basic research on private industry research spending. He finds that a $1 million increase in federal spending results in about a $620,000 increase in industry spending, suggesting strong evidence of a crowd-in effect in the US economy. Aschhoff and Sofka (2009) apply a Tobit model to a dataset including 1149 German enterprises and show that direct public R&D investment and public procurement positively affect private innovation activities, expressed as the share of turnover achieved with new products. Draca (2013), using US firm-level dataset for the 1966–2003 period, shows that defence procurement positively impacts business R&D expenditures, estimating an elasticity of approximately 0.07. Azoulay *et al.* (2019) analyze the impact of National Institutes of Health (NIH) research funding on patenting activities carried out by private biopharmaceutical firms for the 1980–2012 period. Their results show that

[1] For an in-depth review of the effects of demand on private innovative activities, see, among others, Di Stefano *et al.* (2012).

[2] For a survey of different types of public procurement, i.e., regular public procurement and public procurement for innovation, see, among others, Uyarra *et al.* (2020). In addition, recent work stresses how governmental demand has a significant impact on enabling the development and diffusion of selected classes of technologies, e.g., environmental innovations (see, among others, Ghisetti, 2017; Edquist and Zabala-Iturriagagoitia, 2020).

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NIH investments in research areas increase private-sector patenting: a $10 million increase in funding for an area leads to 2.7 additional patents. Crespi and Guarascio (2019), using sectoral data for 24 OECD countries in the 1995–2012 period, analyze the effect of public procurement in creating or consolidating a market and shaping technological change and innovation. Results from Poisson regression techniques show that public procurement positively affects the dynamics of innovation activity captured by industries' patenting activities. Moretti *et al.* (2023), using a country-industry panel dataset for 26 OECD countries considered in the 1987–2009 period, investigate the effect of public defence R&D on business R&D activities. Their result suggests that public investment in R&D positively impacts private R&D: a 10% increase in defence R&D results in a 5.1% increase in private sector R&D the following year. Recently, Rehman *et al.* (2020) investigated the relationship between public and private R&D by taking into account the economic crisis of 2008 for a panel of 10 OECD countries in the 2000–2014 period. Results from a system Genneralized Method of Moments estimation show that public R&D has a positive impact on private R&D in both pre- and post-2008 crisis, with a stronger effect in the pre-crisis period. Considering the little literature on mission-oriented policies, Ziesemer (2021), using a vector error-correction model (VECM) for a panel of seven European countries, shows that a 1% increase in mission-oriented R&D leads to an additional 0.7% for private R&D. Deleidi and Mazzucato (2021), applying an SVAR model to US quarterly data, show a robust crowding-in effect when assessing the impact of MOIPs on business R&D investment: a $1 increase in defence R&D investment leads to an increase of $0.75 of private R&D investment in the same quarter.

Contrarily, other studies have supported the idea that government R&D expenditures crowd out private R&D investment. Lichtenberg (1984) finds that public R&D reduces private R&D investment using US industry-level data for the 1963–1979 period. He concludes that when adding industry and time dummies, an additional dollar of federal R&D crowds out 8 cents of private R&D investment. Wallsten (2000), using a dataset of 369 firms involved in the US Small Business Innovation Research (SBIR) program between 1990 and 1992, estimates a multi-equation model where he finds evidence that public grants crowd-out dollar for dollar firm-financed R&D spending. Guellec and Van Pottelsberghe De La Potterie (2003) claim that defence-related R&D funding has a crowding-out effect on civilian business R&D, while civilian public research is neutral for business R&D for 17 OECD countries in the 1983–1996 period. Cohen *et al.* (2011), using data on US firms for the 1967–2008 period, investigate the relationship between government spending and private investment in R&D using changes in congressional committee chairmanships as a source of exogenous variation in state-level federal expenditures. Their results suggest that fiscal spending shocks are negatively correlated with private investment in R&D, implying a reduction of private R&D by 7–12%. Similarly, Kong (2020) uses US firm-level data for the 1976–2007 period to analyze the effect of government spending on corporate innovation. His results show that firms headquartered in states with increases in government spending significantly reduce their number of patents.

When considering the macroeconomic literature on fiscal multipliers, the impact of discretionary fiscal policies on GDP and its components is evaluated by quantifying the so-called fiscal multiplier. In recent years, several contributions have empirically estimated the magnitude of multipliers, applying different econometric techniques, identification strategies, and model specifications. These have led scholarly-based literature to obtain mixed results that can arise from: (i) different models that are employed, i.e., Dynamic Stochastic General Equilibrium and Vector Autoregression (VAR) models, various single-equation estimation techniques, and subnational geographic cross-section estimates; (ii) different identification strategies to obtain fiscal shocks, namely the recursive approach, the Blanchard and Perotti approach, the sign restriction approach, the narrative approach, and the natural experiment approach; (iii) how multipliers are computed, i.e., cumulative or no-cumulative multipliers; and (iv) several countries' structural characteristics, such as the accumulated public debt, the exchange rate regime, and the openness to trade (Ramey, 2011, 2019; Ilzetzki *et al.*, 2013; Gechert, 2015; Deleidi *et al.*, 2023). The empirical literature on multipliers shows that total government spending is generally found to positively affect the GDP level, with a public expenditure multiplier close to 1 (Blanchard and Perotti, 2002; Ramey,

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2011; Auerbach and Gorodnichenko, 2012; 2017; Caldara and Kamps, 2017).[3] Regarding the effect of different components of public expenditure on GDP, most of these studies distinguish between public consumption and investment without finding unanimous results. While Perotti (2004), Pappa (2009), and Boehm (2020) show that public consumption has a more significant impact than public investment on GDP, Burriel *et al.* (2010), Auerbach and Gorodnichenko (2012), Izquierdo *et al.* (2019), Deleidi (2022), and Petrović *et al.* (2021) find opposite results. Specifically, Perotti (2004), by applying an SVAR model using quarterly data for the 1960–2001 period, finds a peak multiplier of 2.32 for public consumption and 1.68 for public investment in the US economy. Pappa (2009), using the sign restriction identification to quarterly data for the 1970–2007 period, finds a peak multiplier of 2.52 for public consumption and a government investment peak multiplier of 0.23 for the US economy. Boehm (2020), using the LP method for a panel of OECD countries' quarterly data from 2003 to 2016, finds a cumulative multiplier of 0.76 for public consumption and a cumulative investment multiplier of –0.08 after four quarters. On the other hand, Auerbach and Gorodnichenko (2012) estimate an SVAR model for the 1947–2009 period and find a cumulative government investment multiplier equal to 2.39 and a government consumption multiplier of 1.20 after 20 quarterly for the US economy. Burriel *et al.* (2010), applying an SVAR model to US and EU quarterly data considered for the 1981–2007 period, find an impact consumption multiplier of 0.49 in US and 0.86 in EU economies, while an impact investment multiplier of 2 and 1.56 for US and EU economy, respectively. Izquierdo *et al.* (2019), by applying the LP approach to European quarterly data for the period 1987–2014, find a public consumption multiplier of 0.25 and a public investment multiplier equal to 0.80 2 years after the spending shock occurred. They motivate their result by suggesting that the public investment multiplier involves positive spillovers of productive public capital on private capital, i.e., a public investment shock generates a crowding-in effect on private investment (Bom and Ligthart, 2014). Deleidi (2022), by applying an SVAR model to Italian quarterly data for the 1995–2019 period, finds a public consumption multiplier of 1.94 and a public investment multiplier of 4.50 after 10 quarters. Petrović *et al.* (2021), applying both SVAR and the LP approach to Central and East European quarterly data from 1999 to 2015, find a 1-year fiscal cumulative investment multiplier equal to 0.7, while a consumption multiplier of 0.2. Additionally, Auerbach and Gorodnichenko (2012), when distinguishing between US defence and non-defence spending, find no difference between the peak multipliers of the two expenditure components. Ellahie and Ricco (2017), using an SVAR model for the 1959–2012 period, find that non-defence investment provides a strong economic stimulus compared to defence investment. They estimate an impact multiplier of 5.76 for non-defence investment, while the corresponding impact multiplier for defence investment is 0.68 for the US economy. Deleidi *et al.* (2020) and Deleidi and Mazzucato (2021), using the LP approach in 11 European countries, show that government investment is associated with a multiplier close to 1 on impact and a maximum effect close to 3. Finally, when considering the little literature on mission-oriented policies, most studies focus on the US economy.[4] Deleidi and Mazzucato (2021), distinguishing between defence R&D investment and generic public expenditure, find that the former generates the largest effect on the GDP. In particular, applying an SVAR model to US quarterly data, they estimate a defence R&D investment multiplier of 5.76 and a generic expenditure multiplier of 0.63 after 32 quarters. Similarly, De Lipsis *et al.* (2023), applying a rational expectation SVAR on US quarterly data for the period 1947–2017, show that public R&D spending engenders expansionary effects that outperform those of other classes of public spending. From their results emerge that public R&D investments produce a fiscal multiplier of 23.35 after 24 quarters. Antolin-Diaz and Surico (2022), applying a Bayesian SVAR to US quarterly data for the period 1889–2015, find a long-run GDP multiplier equal to 2.08. Their results show that GDP dynamics are most likely driven by government R&D, highlighting an important channel through which fiscal policy can support economic

[3] Several contributions have estimated that the size of fiscal multipliers has been underestimated by about 0.7–1.0 units during the Global Financial and Euro area crises (Blanchard and Leigh, 2014; Fatás and Summers, 2018; Gechert *et al.*, 2019).

[4] Gechert and Heimberger (2022) show that an increase in capital taxation may spur long-term growth if tax revenues are used for higher productive public expenditures.

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growth. Fieldhouse and Mertens (2023), using a LP approach and a narrative identification strategy for public R&D appropriation in the US economy, find that non-defence government R&D produces long-lasting positive effects on several macroeconomic variables, such as potential output, total factor and labor productivity, and patent innovation index. Kantor and Whalley (2022) evaluate the contribution to the economic growth of the space mission by analyzing data from the Cold War era Space Race in the United States. They find that R&D spending on the Space Race had a larger impact than more standard government expenditures. Their results show a local fiscal multiplier for public R&D of 2.4 during the Space Race (1958–1972 period) and 3.8 in the post-Space Race period (after 1972). Ziesemer (2021), using a panel of seven European countries and a VECM, shows that a 1% increase in mission-oriented R&D leads to an additional 0.45% for total factor productivity and 0.56% for GDP.

In recent years, there has been extensive use of non-linear models to test whether the effects of fiscal policies on GDP change in different states of the economy, namely during economic recessions and expansions. Results are ambiguous, even when state-dependent multipliers are estimated. Indeed, Auerbach and Gorodnichenko (2012) find that government spending multipliers are higher in recession than in expansion periods for the US economy. Several contributions find similar results using alternative empirical methods and variables describing the state of the business cycle (see, among others, Candelon and Lieb, 2013; Fazzari *et al.*, 2015; Riera-Crichton *et al.*, 2015; Auerbach and Gorodnichenko, 2017; Amendola, 2023). Other contributions point out that state-dependent multipliers emerge only when deep recessions and strong expansionary periods are considered (Caggiano *et al.*, 2015; Boitani *et al.*, 2022). Ramey and Zubairy (2018), using a threshold LP for the US economy, estimate acyclical spending multipliers, while Alloza (2022), estimating non-linear SVAR and threshold LP models, finds higher government spending multipliers in expansion than in recessions in the United States. Recently, Berge *et al.* (2021) argue that the inconsistencies found in the literature might arise from the way recessionary and expansionary states are defined. They show that government spending multipliers are higher when unemployment rates increase than when they decrease. On the contrary, they show that the magnitude of multipliers does not depend on whether the unemployment rate is below or above its trend.[5]

3. Data and methodology

3.1. Data

To detect the effect of generic fiscal policies and those targeted on R&D spending on GDP and business R&D, we use yearly data provided by OECD, using the Main Science and Technology Indicators (MSTI) database, Economic Outlook, and National Accounts databases. Our analysis is based on 15 countries: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Portugal, Spain, the United Kingdom, and the United States. The analysis is conducted using yearly macroeconomic data considered for the period 1981–2017.[6] We use the following variables: GDP (Y), government consumption and investment expenditures (G), private R&D expenditures performed and financed by the private sector ($R\&D$), and the real long-term interest rate (i). Specifically, to analyze the effects that different classes of public spending exert on the variables of interest, we break down government spending G in government expenditure in research and development (G_I) and the sum of consumption and investment net of public spending on research and development (G_RES). The variables are expressed in real terms using the GDP deflator and are converted to USD dollars using the PPP index. All variables are expressed at logarithmic levels. Details on the construction of the variables and data sources are provided in Supplementary Appendix 1, Table 1.1.

[5] For an in-depth literature review on this topic, see Gechert and Rannenberg (2018).

[6] Even if studies estimating responses of macroeconomic variables to fiscal shocks tend to utilize high-frequency data to refine the identification of fiscal shocks, there could be some benefits in using annual data. Fiscal plans for government expenditure typically follow an annual cycle and thus identified annual fiscal shocks may be better aligned with the frequency at which governments make decisions. Additionally, yearly data reduces the role of anticipation effects (Bénétrix and Lane, 2015; Auerbach and Gorodnichenko, 2017).

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3.2. Methodology

The LP method (Jordà, 2005) is used to detect the effect of public R&D and generic fiscal expenditures on private R&D and GDP. As advocated by Jordà (2005) and Auerbach and Gorodnichenko (2017), there are multiple advantages in using the LP method to estimate impulse response functions (IRFs): (i) it does not impose dynamic restrictions on the IRFs because it estimates separate functions for each horizon; (ii) it is more robust to misspecification; and (iii) it easily accommodates experimentation with highly nonlinear and flexible specifications.

The LP approach entails the estimation of individual single regressions in which the variable of interest is considered in each horizon following the realization of the shock. This method can be formalized as follows:

$$y_{t+h} = \alpha_h + \beta^h x_t + \psi^h (L)\, z_{t-1} + \varepsilon_{i,t+h};\, for\, h = 0, 1, 2, \ldots, H. \tag{1}$$

where y is the variable of interest considered at each horizon $h = 0, 1, 2, \ldots H$; z_{t-1} is a vector of control variables; $\psi^h(L)$ is a polynomial in the lag operator, and x_t is the selected fiscal variable shock. β^h is the response of y at horizon $t+h$ to the shock at time t. Thus, one constructs the impulse responses as a sequence of the β^h's estimated in a series of single regressions for each horizon $h = 0, 1, \ldots H$.

In addition, following the works by Ramey (2016), Auerbach and Gorodnichenko (2017), Ramey and Zubairy (2018), and Deleidi *et al.* (2023), we use an innovative econometric technique that combines the LP approach with shocks estimated using Structural Vector Autoregressive modeling. Particularly, we first identify government spending shocks ($w_{i,t}$) associated with *G_I* and *G_RES* in an SVAR model, and then we introduce those shocks in LP equation. Government spending shocks are identified using a recursive identification strategy, based on a Cholesky factorization, in a four-equation SVAR model where: public investment in R&D (*G_I*) is ordered first; generic fiscal expenditures (*G_RES*) are ordered second, gross domestic product (Y) is ordered third, and the real interest rate (i) is the last ordered variable. This identification strategy implies that: (i) public R&D government investment (*G_I*) does not respond to other variables included in the model within the year, namely, it is the most exogenous variable; (ii) more generic government spending (*G_RES*) may react contemporaneously only to *G_I*. The first assumption is justified by the fact that public R&D investments are strategic investments that reflect political and industrial priorities and are not influenced by the current economic activity (Deleidi and Mazzucato, 2021; Ciaffi *et al.*, 2022; Moretti *et al.*, 2023).[7] The second assumption is based on the idea that government spending—defined as the sum of consumption and investment—takes more than one period to respond to macroeconomic conditions (Blanchard and Perotti, 2002; Beetsma *et al.*, 2009; Born and Muller, 2012; Bénétrix and Lane, 2015; Konstantinou and Partheniou, 2021). Following the more recent literature on monetary policy, interest rate (i) is the last ordered variable since we assume a monetary policy reaction function and a private sector that responds slowly to changes in monetary policy variables (Castelnuovo and Surico, 2010; Cucciniello *et al.*, 2022).[8]

Once government spending shocks ($w_{i,t}$) are identified, they are introduced in the LP equation to estimate the IRFs by substituting x_t in equation (1) with $w_{i,t}$. The estimated model is formalized as follows in equation (2):

$$y_{i,t+h} = \alpha_i + \delta_\tau + \beta^h w_{i,t} + \sum_{j=1}^{p} \vartheta_j^h\, z_{i,t-j} + \varepsilon_{i,t+h} \tag{2}$$

where i and t index countries and time; α_i and δ_τ are country and time fixed effects; y is the variable of interest considered at each horizon $h = 0, 1, \ldots H.$; $w_{i,t}$ are the structural shocks obtained

[7] Although not focused on R&D expenditure, Perotti (2004) and Ilzetzki *et al.* (2013) assume government investment more exogenous than government consumption.

[8] The results are unchanged if we also include private R&D investment in the VAR model to identify fiscal policy shocks. These findings are available upon request.

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through the recursive identification; $z_{i,t-j}$ contains the control variables.[9] Specifically, we estimate equation (2) to assess the effects of the fiscal expenditure variables (G_I and G_RES) on GDP (Y) and private R&D ($R\&D$).

When models include variables in log-level or in rate of growth, the β^h coefficient in equation (2) represents the elasticity of the variables of interest y to the selected fiscal variables. Therefore, to estimate fiscal multipliers, it is necessary to multiply the β^h coefficient by an *ex-post* conversion factor equal to the average value of the variable of interest y divided by the selected fiscal variable.[10] Contrarily, when following the procedure put forward by Owyang *et al.* (2013), fiscal policy shocks are rescaled by the ratio between the selected fiscal variable (G_I and G_RES) and y (Y and $R\&D$) at each point in time, so that changes in these variables are measured as a percentage of the dependent variable (Y or $R\&D$). In this way, the β^h coefficients in equation (2) directly represent the fiscal multiplier.

Additionally, following Spilimbergo *et al.* (2009), Ramey (2016), and Ramey and Zubairy (2018), we estimate the cumulative multipliers associated with different fiscal shocks. Specifically, the cumulative effects are obtained by dividing the cumulative response of the variable of interest y (Y and $R\&D$) by the cumulative government expenditure change that occurred during the observed period (Spilimbergo *et al.*, 2009; Gechert and Rannenberg, 2018). In this way, the cumulative effects allow us to study the response of GDP and private R&D per unit increase in government spending. Cumulative multipliers address the relevant policy question because they measure the cumulative GDP gain relative to the cumulative government spending during a given period (Ramey and Zubairy, 2018). This measure also allows for studying the persistence of fiscal policy shocks in evaluating the effects on private economic activity (Woodford, 2011; Caggiano *et al.*, 2015).

The IRFs represent the response of the variable of interest ($y_{i,t+h}$) to a shock of the fiscal variables realized at period t ($x_{i,t}$). Formally, the IRFs can be represented in equation (3):

$$\beta^h = \frac{\Delta y_{i,t+h}}{\Delta x_{i,t}} \tag{3}$$

On the other hand, as shown in equation (4), the cumulative effect is estimated by dividing the cumulative change in the variable of interest $\Delta y_{i,t+h}$ by the cumulative change in the fiscal expenditure $\Delta x_{i,t+h}$. Specifically, we have:

$$\beta^h_{cum} = \frac{\sum_{h=0}^{n} \Delta y_{i,t+h}}{\sum_{h=0}^{n} \Delta x_{i,t+h}} \tag{4}$$

Thus, cumulative coefficients can assess whether a permanent increase in the fiscal variables produces persistent and long-lasting effects on the variables of interest. The cumulative fiscal multiplier is estimated in three steps (Ramey and Zubairy, 2018; Petrović *et al.*, 2021). First, the cumulative change of the dependent variable (Y and $R\&D$) is estimated between t and $t+h$ in equation (2). Similarly, as a second step, the cumulative change of government expenditure between t and $t+h$ is calculated by regressing the same equations (equation 2) with the government expenditure (G_I and G_RES) as the dependent variable. Finally, the cumulative multiplier is computed as the ratio between the coefficients β^h estimated in steps one and two multiplied by the *ex-post* conversion factor.

To provide a robust picture of our findings, we follow the main model specification found in the fiscal policy literature (Blanchard and Perotti, 2002; Auerbach and Gorodnichenko, 2012; Owyang *et al.*, 2013; Ramey and Zubairy, 2018), by considering four different specifications of models described in equation (2). While we use variables in growth rates in model 1, variables

[9] The control variables included in equation (2) are GDP (Y), total public expenditure (G), private investment in R&D ($R\&D$), and real interest rate (i). In all model specifications, a lag equal to 1 ($j = 1$) is considered (Auerbach and Gorodnichenko, 2017). The results are unchanged if we include two lags. These findings are available upon request.

[10] The ratios used in the *ex-post* transformation from elasticities to partial derivatives are calculated as follows: $R\&D/G\_I$; $R\&D/G\_RES$; Y/G_I; Y/G_RES. They assume the following values respectively: 1.48; 0.04; 167.67; and 4.30.

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are in log-level in model 2 (Blanchard and Perotti, 2002). Using variables in log-level, we can preserve any cointegration relationship that may exist among considered variables (Auerbach and Gorodnichenko, 2012; Caggiano *et al.*, 2015; Kilian and Lütkepohl, 2017). As a robustness check, we also estimate two additional models. We perform an *ex-ante* conversion procedure in model 3, where variables are expressed in growth rates following Owyang *et al.* (2013). In doing so, we avoid any potential biases that could arise from the use of a constant sample average, as in the *ex-post* conversion procedure.[11] Finally, variables are in log-level in model 4, and we also add a country-specific time trend as a control variable.

4. Findings

This section shows our findings by displaying the estimated IRFs and cumulative fiscal multipliers. We evaluate LP for 5 years ahead ($h = 5$) for four different model specifications,[12] defined in Section 3.2, considering as dependent variables the GDP (Y) and the private R&D ($R\&D$). In all figures reported below, we have displayed both the dynamics of government spending (G_I and G_RES) as well as the corresponding responses of the GDP (Y) and the private R&D ($R\&D$). We also report the results of the corresponding cumulative multipliers.

Figures 1 and 2 plot the IRFs of Models 1–4, whereas the results of cumulative fiscal multipliers are reported in Table 1. IRFs for model 1, model 2, and model 4 represent the elasticity of the variables of interest (Y and $R\&D$) to the selected fiscal variables shocks, namely G_I and G_RES. The IRFs for model 3, reported in Figure 2, represent the fiscal multipliers. By construction, the government expenditure shocks are equal to 1% on impact, whereas their dynamic changes throughout the selected period for the different model specifications. The estimated IRFs show that public expenditure shocks are persistent, as reflected in the positive values 5 years after the initial shock. Furthermore, the IRFs suggest that the components of public spending (both public investment in R&D and non-innovation expenditure) produce persistent effects on the level of economic activity. The impact on GDP and private R&D is positive and statistically significant even 5 years after the initial shock.

Notably, the cumulative multiplier reported in Table 1 shows that public investment in R&D generates the largest effect on GDP compared to more generic expenditure. Looking at the impact of public R&D investment (G_I) in Table 1, the effects on GDP are significant at all considered horizons. The impact multipliers range from 5.26 (model 3) to 8.3 (model 2). Five years after the initial shock, the multipliers are still positive and statistically significant, ranging from 10 (Models 1 and 3) to 15 (model 2). Looking at the effects of more generic public spending (G_RES), the effects on GDP are lower than those generated by public R&D investment, but they are positive and significant. The impact multipliers range from 0.8 (model 1) to 1.11 (model 4). Five years after the initial shock, multipliers are still positive and statistically significant, assuming values ranging from 1 (Models 1 to 3) to 1.4 (model 4). When we analyze the effects that the two selected classes of government expenditures—G_I and G_RES—have on private R&D, public investment in R&D generates a stronger crowding in effect than generic public expenditures (see Table 1).[13]

Our results show that an increase in government expenditure generates positive and persistent effects on the level of output and private R&D. The multipliers associated with public R&D are greater than those found in the fiscal policy literature that focuses on the different classes of government expenditure (Gechert, 2015; Deleidi *et al.*, 2023). Indeed, many studies show that total spending multipliers are close to the unit, ranging between 0.8 and 1.5 (Ramey, 2011, 2016; Auerbach and Gorodnichenko, 2012; Caldara and Kamps, 2017).

[11] Another approach to circumvent potential biases is applied by Ramey and Zubairy (2018) following Gordon and Krenn (2010). They divide all variables by a measure of the trend or potential GDP. However, this approach has been questioned because potential output is sensitive to business cycle fluctuations (Auerbach and Gorodnichenko, 2017; Coibion *et al.*, 2017).

[12] A time horizon of 5 years is more appropriate than a longer one since the LP approach tends to provide both erratic and significant oscillating responses at longer horizons (Ramey and Zubairy, 2018, p. 872).

[13] Even when employing a different identification strategy by ordering G_RES before G_I, public investment in R&D produces a stronger effect on GDP and private R&D than generic public expenditures. Findings are available in the Supplementary Appendix 2, Tables 2.1 and 2.2.

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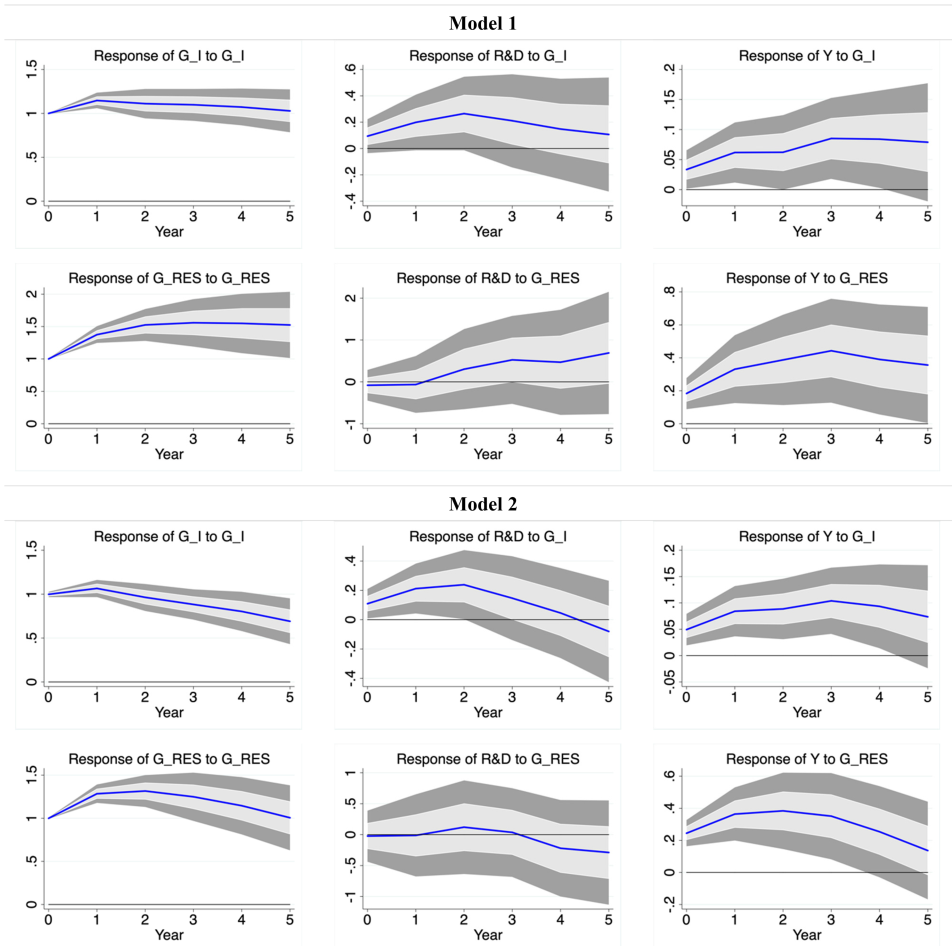

Figure 1. Impulse response functions, models 1 and 2. Shaded areas represent 68% and 95% confidence intervals.

When the literature considers government consumption and investment separately, many studies recognize the superiority of government investment compared to government consumption. Indeed, while public investment multipliers range from 1.3 to 2, government consumption multipliers have a value lying between 0.8 and 1.2 (Gechert, 2015). In line with the work of Deleidi and Mazzucato (2021) and De Lipsis *et al.* (2023) on the US economy, our findings show that public investment in R&D can produce a significant multiplicative effect on economic activity. Thus, our findings show that public investment in R&D can produce a larger fiscal multiplier and determine a stronger direct crowding-in effect than more generic public expenditures, also in countries with an economic structure and context different from the US economy.

The high value assumed by the cumulative multiplier might be motivated by the fact that this direct government investment in R&D is aimed at creating new markets, promoting structural change in the economic system, and involving different sectors and actors. Such kinds of investments can increase business expectations about where future growth opportunities might lie, stimulating private investment that otherwise would not have occurred (Mowery, 2012; Mazzucato, 2016; Allen and Tandberg, 2021).

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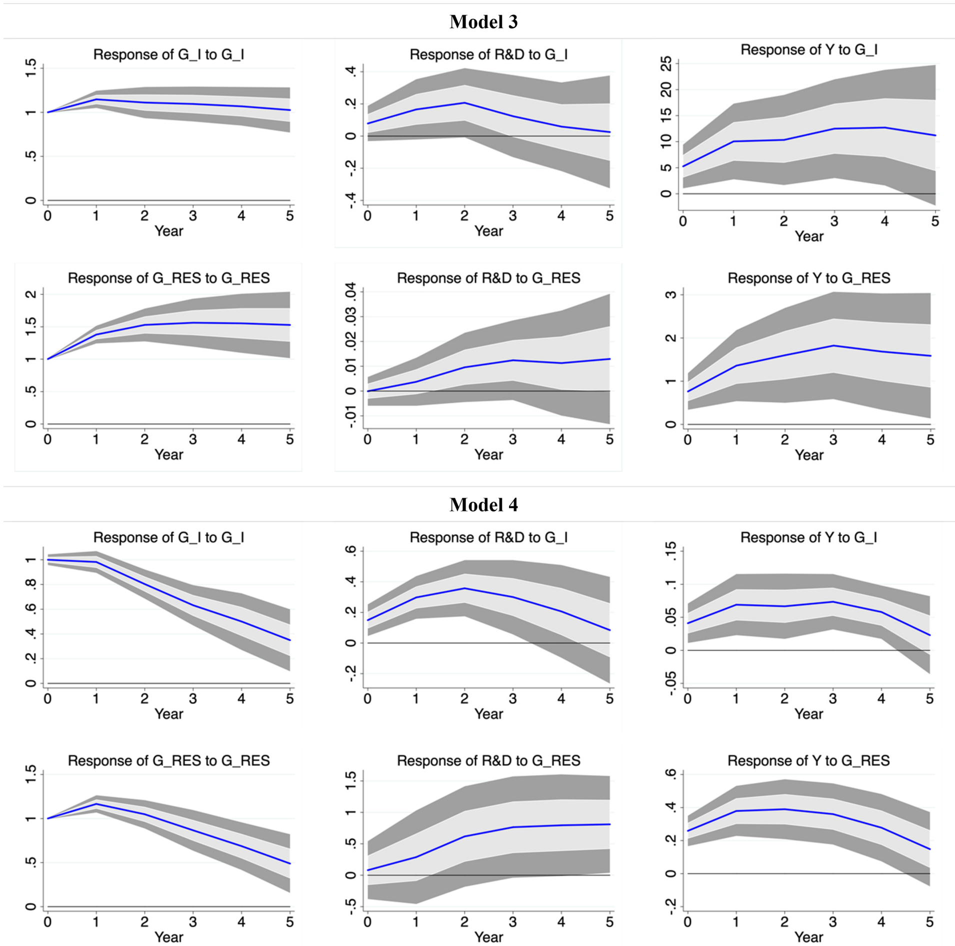

Figure 2. Impulse response functions, models 3 and 4. Shaded areas represent 68% and 95% confidence intervals.

5. Fiscal foresight

Fiscal foresight plays a fundamental role in the fiscal multiplier literature (Blanchard and Perotti, 2002; Ramey, 2011; Auerbach and Gorodnichenko, 2012). Due to decision and implementation lags of fiscal policy, a certain amount of time usually elapses between the moment in which fiscal policy is announced and the moment it is implemented. This entails that private agents may modify their consumption and investment expenditures when receiving information on future changes in fiscal expenditures. Econometrically, when only government expenditure is included in the model, errors can arise because relevant variables—variables capturing fiscal foresight—are omitted and this could lead to biased estimates. Thus, the inclusion of variables capturing fiscal foresight isolates what the literature has defined as an unanticipated or unexpected fiscal policy shock (Auerbach and Gorodnichenko, 2012). We provide estimations of fiscal multipliers by introducing fiscal expenditure expectations in our models to consider this issue.

To identify unanticipated government spending shocks, we follow Auerbach and Gorodnichenko (2012, p. 16) by augmenting our VAR model with the government spending forecasts ($\Delta G^F_{t|t-1}$). We use the forecasts provided by the OECD in the Economic Outlook. Specifically, we use the forecasts made at $t-1$ for the growth rate of real government purchases for

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Table 1. Cumulative fiscal multipliers. Significant estimates are in bold

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Model 1						
Shock to G_I						
Y	**5.60**	**7.43**	**8.10**	**9.34**	**10.10**	**10.55**
R&D	**0.139**	**0.201**	**0.253**	**0.261**	0.250	0.234
Shock to G_RES						
Y	**0.79**	**0.93**	**0.99**	**1.06**	**1.06**	**1.05**
R&D	−0.003	−0.003	0.002	**0.005**	0.007	0.009
Model 2						
Shock to G_I						
Y	**8.30**	**10.86**	**12.31**	**13.99**	**14.93**	**15.31**
R&D	**0.161**	**0.230**	**0.272**	**0.266**	0.235	0.183
Shock to G_RES						
Y	**1.05**	**1.13**	**1.16**	**1.17**	**1.12**	1.04
R&D	−0.001	−0.001	0.001	0.001	−0.001	−0.002
Model 3						
Shock to G_I						
Y	**5.26**	**7.14**	**7.88**	**8.77**	**9.38**	**9.63**
R&D	**0.078**	**0.113**	**0.138**	0.132	0.117	0.102
Shock to G_RES						
Y	**0.76**	**0.89**	**0.95**	**1.02**	**1.03**	**1.03**
R&D	0.000	0.002	**0.005**	**0.007**	**0.008**	0.009
Model 4						
Shock to G_I						
Y	**6.87**	**9.31**	**10.64**	**12.28**	**13.19**	13.01
R&D	**0.221**	**0.333**	**0.427**	**0.477**	**0.494**	0.483
Shock to G_RES						
Y	**1.11**	**1.27**	**1.37**	**1.46**	**1.50**	**1.48**
R&D	0.003	0.007	**0.013**	**0.018**	**0.023**	**0.027**

time t.[14] Technically, we augment our VAR model by applying a recursive identification strategy where government spending forecasts ($\Delta G_{t|t-1}$) are ordered first. In this way, we can identify unanticipated fiscal shocks ($w_{i,t}^{unexp}$). This helps purify public expenditure shocks from their potentially predictable component. Following the procedure carried out for the baseline models, the identified unexpected fiscal shocks $w_{i,t}^{unexp}$ are included in the LP equation as our measure of discretionary fiscal policy to estimate IRFs. Additionally, in this case, government spending forecasts ($\Delta G_{t|t-1}^{F}$) are also incorporated in the LPs equation to control for their effect on the level of economic activity (Boehm, 2020; Deleidi *et al.*, 2023). Therefore, we estimate the following model:

$$y_{i,t+h} = \alpha_i + \delta_\tau + \beta^h w_{i,t}^{unexp} + \gamma^h \Delta G_{i,t|t-1}^{F} + \sum_{j=1}^{p} \vartheta_j^h z_{i,t-j} + \varepsilon_{i,t+h} \tag{5}$$

where i and t index countries and time; α_i and δ_τ are country and time fixed effects; y is the variable of interest considered at each horizon $h = 0, 1, \ldots H$; $w_{i,t}^{unexp}$ is the unanticipated government spending shocks obtained through the recursive identification; $z_{i,t-j}$ contains the control variables. Specifically, we estimate equation (5) by considering the effects of the fiscal expenditure variables (G_I and G_RES) on GDP (Y) and private R&D ($R\&D$). In all figures reported below, we have displayed both the dynamics of government spending (G_I and G_RES) as well as the corresponding responses of the GDP (Y) and private R&D ($R\&D$). We also report the results of the correspondent cumulative fiscal multipliers.

Figures 3 and 4 plot the IRFs of Models 1–4 augmented by fiscal expectation, whereas the results of cumulative fiscal multipliers are reported in Table 2. We find that the main result of

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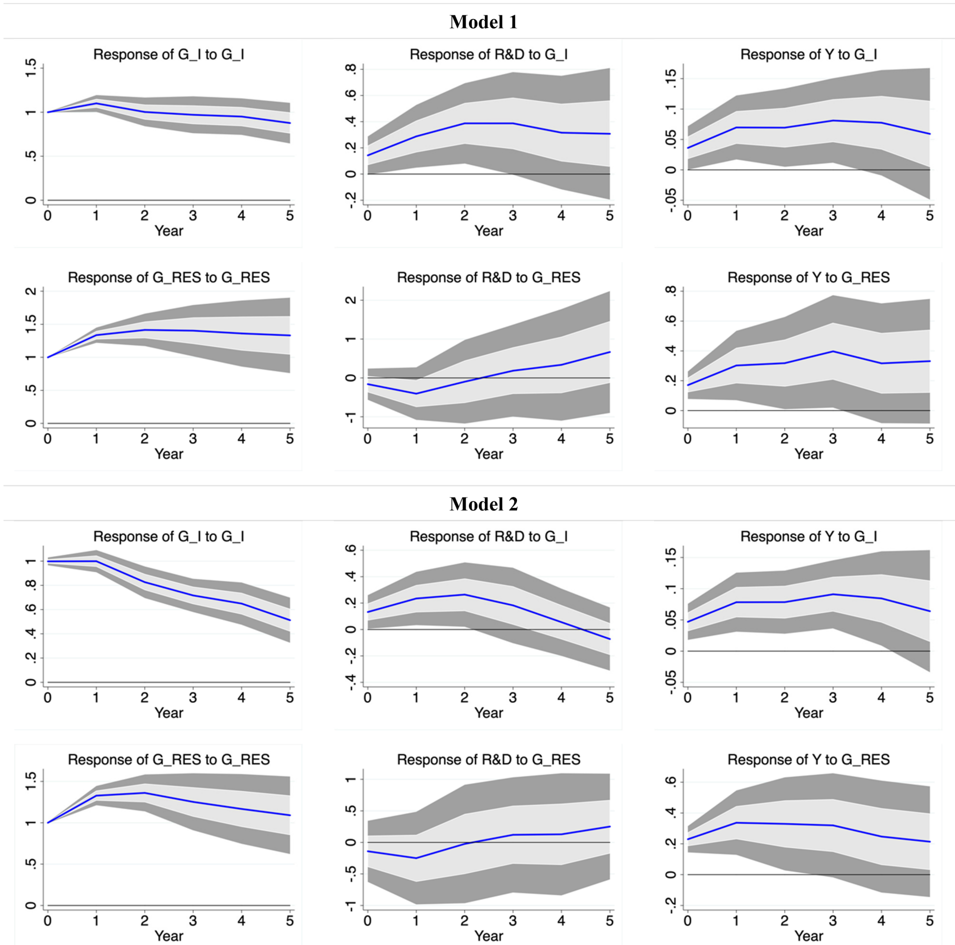

Figure 3. Impulse response functions, models 1 and 2 with fiscal expectations $\Delta G^F_{t|t-1}$. Shaded areas represent 68% and 95% confidence intervals.

our empirical analysis is confirmed: even with the introduction of expectations, the components of public spending (both public investment in R&D and non-innovation expenditure) produce persistent effects on the level of economic activity. Additionally, public investment in R&D (G_I) generates the largest impact on GDP and private R&D than the one engendered by more generic public expenditures. IRFs in Figures 3 and 4 show that the government investment shocks are equal to 1% on impact, whereas their dynamic changes throughout the selected period for the different model specifications. The estimated IRFs are all positive, reflecting a high persistence in the shocks and the GDP responses. Even when introducing expectations, the components of public spending (both public R&D and non-innovation expenditure) produce persistent effects on the level of economic activity, and the impact on GDP is statistically significant even 5 years after the initial shock. The results show that public investment in R&D generates the largest effect on GDP than the one produced by more generic public expenditures.

Looking at the effect of public R&D investment (G_I) in Table 2, the effects on GDP are significant at all considered horizons. The impact multipliers range from 6 (model 1) to 7.8 (model 2). Five years after the initial shock, the multipliers are still positive and statistically significant, ranging from 8 (model 4) to 15 (model 2). Looking at the effects of generic public spending

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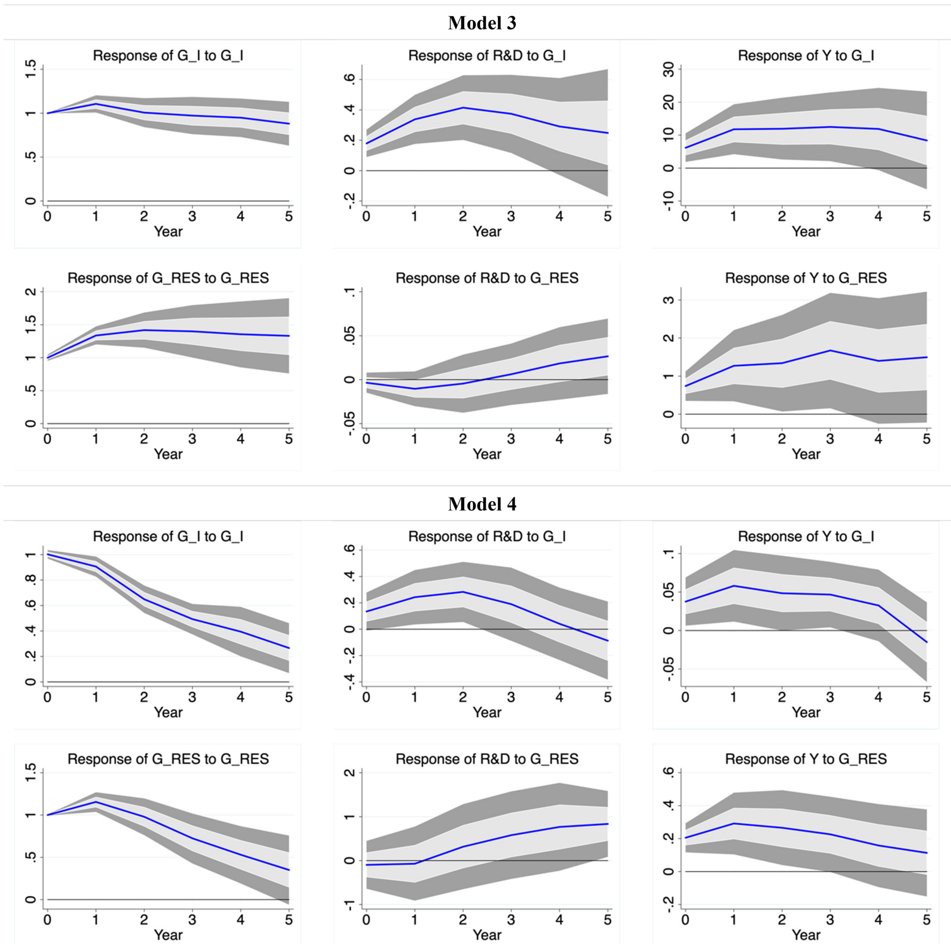

Figure 4. Impulse response functions, models 3 and 4 with fiscal expectations $\Delta G^{F}_{t|t-1}$. Shaded areas represent 68% and 95% confidence intervals.

(*G_RES*), the effects on GDP are lower than those generated by public R&D investment, but they are positive and significant. The impact multipliers range from 0.8 (Models 1 and 3) to 1 (model 2). Five years after the initial shock, multipliers are still positive and statistically significant, assuming an average value of 1 in all considered models. When we analyze the effects that public expenditure—*G_I* and *G_RES*—have on private R&D (*R&D*), also in this case, public investment in R&D produces a stronger positive effect than generic public expenditures (see, Table 2).

Summing up, we can affirm that our results are robust to the inclusion of the forecasts into the model and, therefore, to potential problems related to the predictability of public spending shocks. The results suggest that even when controlling for fiscal expectations, the components of public spending (both public investment in R&D and non-innovation government expenditure) produce persistent effects on the economic activity, and the impact on the GDP level is statistically significant even 5 years after the initial shock. Public investment in R&D (*G_I*) generates the largest multiplicative effect on GDP compared to more generic public expenditure. Even when controlling for fiscal expectation, public investment in R&D produces a positive impact on the business investment in R&D, which is much greater than the effect produced by generic government expenditures.

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Table 2. Cumulative fiscal multipliers with fiscal expectations $\Delta G^F_{t|t-1}$. Significant estimates are in bold

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Model 1—$\Delta G^F_{t\|t-1}$						
Shock to G_I						
Y	**6.04**	**8.40**	**9.42**	**10.51**	**11.03**	**11.07**
R&D	**0.217**	**0.314**	**0.406**	**0.457**	**0.469**	**0.479**
Shock to G_RES						
Y	**0.75**	**0.90**	**0.92**	**1.01**	**1.01**	**1.02**
R&D	−0.007	**−0.011**	−0.008	−0.004	−0.001	0.003
Model 2—$\Delta G^F_{t\|t-1}$						
Shock to G_I						
Y	**7.87**	**10.48**	**12.03**	**13.92**	**14.80**	**15.74**
R&D	**0.205**	**0.285**	**0.346**	**0.356**	0.322	0.262
Shock to G_RES						
Y	**0.99**	**1.08**	**1.08**	**1.10**	**1.07**	**1.04**
R&D	−0.004	−0.007	−0.005	−0.002	−0.001	0.001
Model 3—$\Delta G^F_{t\|t-1}$						
Shock to G_I						
Y	**6.16**	**8.54**	**9.64**	**10.40**	**10.80**	**10.61**
R&D	**0.179**	**0.246**	**0.300**	**0.320**	**0.318**	**0.312**
Shock to G_RES						
Y	**0.74**	**0.86**	**0.90**	**1.00**	**1.00**	**1.01**
R&D	−0.004	**−0.006**	−0.005	−0.002	0.001	**0.004**
Model 4—$\Delta G^F_{t\|t-1}$						
Shock to G_I						
Y	**6.26**	**8.43**	**9.27**	**10.05**	**10.33**	8.73
R&D	**0.207**	**0.306**	**0.400**	**0.431**	0.400	0.335
Shock to G_RES						
Y	**0.90**	**1.01**	**1.03**	**1.10**	**1.14**	1.16
R&D	−0.009	−0.01	−0.007	0.000	**0.005**	**0.012**

6. Conclusion

Our paper contributes to the ongoing debate among international institutions and academic scholars regarding the role of government expenditure in boosting the level of economic activity and innovation. We assess the macroeconomic effect of government R&D investment and more generic fiscal policies by quantifying the GDP and private R&D investment multipliers. To do this, we apply panel techniques based on the LP approach to a dataset of 15 OECD countries for the period 1981–2017 (Auerbach and Gorodnichenko, 2017; Ramey and Zubairy, 2018; Deleidi *et al.*, 2023). We combine the LP approach with fiscal policy shocks computed using SVAR models. Specifically, we first identify fiscal policy shocks through an SVAR model by applying a Cholesky factorization where public investment in R&D spending is ordered first, and generic fiscal expenditures are ordered second. Secondly, once government spending shocks are computed, they are introduced in the LP equations to estimate the IRFs and derive fiscal multipliers. Finally, in line with the empirical literature on fiscal multipliers, we consider the role played by fiscal foresight using government expenditure expectations released by the OECD economic outlook.

Our findings show that expansionary fiscal policies generate positive and persistent impacts on the GDP level and the two selected classes of government expenditures produce a crowding-in effect on business investments in R&D. Our results show that government investment in R&D generates a higher impact on GDP and business investment in R&D than the one produced by more generic public expenditures. The estimated multipliers for GDP show that innovation-oriented fiscal policies generate impact multipliers larger than 5 in all model specifications that reach significant 5 year multipliers of 10.5, 15.3, 9.6, and 13 in Models 1, 2, 3, and 4, respectively. Conversely, generic public expenditures assume impact multipliers ranging between 0.8 and 1 according to the different model specifications that reach 5 year multipliers close to one in all model specifications. When evaluating the effect of different fiscal policies on private R&D,

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estimated R&D multipliers show that public investment in R&D generates a larger crowding-in effect than the one associated with more generic public expenditures. Our findings are confirmed even when we consider fiscal foresight. Further development of this research will assess: (i) the impact of public R&D investment on private consumption and investment, and labor market dynamics; (ii) non-linear fiscal multipliers; and (iii) the impact on the sectoral composition of output.

Our findings also have policy implications for fostering economic recovery after the COVID-19 pandemic and coping with the economic stagnation that advanced economies have experienced in the last decades. Notably, in line with the policy prescriptions put forward by the International Monetary Fund (IMF) (2021) and European Commission (2018a), our findings show that governments should invest public resources in R&D activities since they can generate a more significant multiplicative effect than more standard fiscal policies. Furthermore, these strategic innovation policies can promote long-term structural transformations of the economy by crowding-in private R&D investment and creating new market opportunities beyond the existing technological paradigms.

Supplementary Data

Supplementary materials are available at *Industrial and Corporate Change* online.

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