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DIRECTED INNOVATION POLICIES AND THE SUPERMULTIPLIER: NEW EVIDENCE

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ABSTRACT

This paper investigates the macroeconomic effects of public R&D investment in the US economy from 1947 to 2018, employing alternative empirical approaches based on Structural VARs, pure shocks derived from a counterfactual VAR, and Instrumental-Variable Local Projections. The analysis provides robust evidence consistent with the findings of Deleidi and Mazzucato (2021), confirming that public R&D exerts strong and persistent expansionary effects on economic activity. Examining the fiscal policy transmission mechanisms, the results indicate that public R&D generates significant crowding-in effects on private R&D, non-residential investment, and consumption, thereby supporting the existence of a Supermultiplier effect. When total public R&D is broken down into military and civil components, and pure shocks are estimated, both spending categories yield statistically similar macroeconomic effects. Finally, sub-sample analyses confirm our findings and show that the magnitude of public R&D multipliers remains broadly comparable over time. Overall, the findings highlight the macroeconomic importance of public R&D as an effective tool for sustaining long-term economic growth.

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Directed Innovation Policies and the Supermultiplier: New Evidence

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Abstract:

This paper investigates the macroeconomic effects of public R&D investment in the US economy from 1947 to 2018, employing alternative empirical approaches based on Structural VARs, pure shocks derived from a counterfactual VAR, and Instrumental-Variable Local Projections. The analysis provides robust evidence consistent with the findings of Deleidi and Mazzucato (2021), confirming that public R&D exerts strong and persistent expansionary effects on economic activity. Examining the fiscal policy transmission mechanisms, the results indicate that public R&D generates significant crowding-in effects on private R&D, non-residential investment, and consumption, thereby supporting the existence of a Supermultiplier effect. When total public R&D is broken down into military and civil components, and pure shocks are estimated, both spending categories yield statistically similar macroeconomic effects. Finally, sub-sample analyses confirm our findings and show that the magnitude of public R&D multipliers remains broadly comparable over time. Overall, the findings highlight the macroeconomic importance of public R&D as an effective tool for sustaining long-term economic growth.

JEL Codes: C32; E11; E62; O30; O25;

Keywords: Public R&D; Fiscal multipliers; Mission-Oriented Innovation policy; Structural VAR; Local projections.

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1. Introduction

The prolonged stagnation of advanced economies in recent decades has revived interest in the role of discretionary fiscal policy in stimulating GDP and its components. The literature on fiscal multipliers shows that expansionary fiscal measures can effectively support economic activity, with their composition proving crucial for their overall impact on output (Auerbach and Gorodnichenko, 2012; Deleidi et al., 2023). At the same time, the recent resurgence of industrial policy has revived the debate on public investment in research and development (R&D), particularly when directed towards strategic sectors and missions capable of fostering innovation and technological change (Mazzucato and Kattel, 2020; Van Reenen, 2020).

Within this framework, increasing attention has been paid to Mission-Oriented Innovation Policies (MOIPs) – strategic public investments with a high content of R&D investment that aim to address major societal and technological challenges. The MOIPs approach to innovation, grounded in the concept of the entrepreneurial state (Mazzucato, 2013, 2018), views government not merely as a fixer of market failures but as a proactive agent that shapes and creates markets, mobilising innovation to achieve transformative objectives. MOIPs thus operate as modern industrial policies that leverage frontier knowledge to pursue collective goals, namely ‘big science deployed to meet big problems’ (Mazzucato, 2018, p. 804). Despite this growing attention, evidence from the IMF (2024) shows that public R&D investment has gradually declined over the past few decades relative to private spending. In recent years, however, many major economies have reintroduced more directed industrial strategies, driven by economic and national security concerns, thereby raising important questions about their long-term effectiveness (IMF, 2024).

Several scholars have examined the impact of government R&D investment. Recent studies demonstrate that targeted innovation expenditures can generate significant macroeconomic effects by stimulating GDP growth, crowding in private R&D, and fostering innovation more effectively than standard fiscal measures (Deleidi and Mazzucato, 2021; Moretti et al., 2025). This strand of research builds on the theoretical framework developed by Deleidi and Mazzucato (2019), who introduced the concept of MOIPs within the Sraffian Supermultiplier model of growth. Subsequent empirical analyses have further tested and developed these insights. Deleidi and Mazzucato (2021), applying a Structural Vector Autoregressive (SVAR) model to US quarterly data for the period 1947‒2018, show that military R&D investment can produce a larger multiplicative effect compared with standard fiscal policy. De Lipsis et al. (2022) corroborate these findings by applying a rational expectations SVAR model on US data.[1] Ciaffi et al. (2024a), using an SVAR model over the period 1948–2019, analyse the effects of public and private innovation spending on productivity in the US, finding that public expenditure exerts a stronger positive impact on productivity and crowds in private R&D. In parallel, some scholars from different theoretical backgrounds have produced complementary evidence consistent with these findings for the US. For instance, Antolin-Diaz and Surico (2025) employ a Bayesian SVAR on US quarterly data from 1889 to 2015, identifying government spending shocks through the military news series developed by Ramey and Zubairy (2018). They estimate a long-run GDP multiplier in the 1.7–2 range and show that government R&D spending is the main driver of GDP dynamics, underscoring a key channel through which fiscal policy can foster long-run growth. Fieldhouse and Mertens (2023), by using a local projection approach and a narrative identification strategy for public R&D appropriation in the US economy, find that public R&D produces long-lasting positive effects on GDP, potential output, and total factor and labour productivity. Kantor and Whalley (2025) evaluate the contribution to the economic growth of the space mission by analysing data from the Cold War era Space Race in the US. They find relatively modest fiscal multipliers – around 0.3 during the Space Race and 0.4 in the post–Space Race period – suggesting positive but limited macroeconomic effects.[2] Recent analyses have extended the studies carried out on the US economy to other pools of countries. Ciaffi et al. (2022, 2024c) confirm the larger multiplicative effects of government R&D investment on GDP by focusing on a panel of G7

[1] The preliminary analysis of such work has been also reported in Deleidi et al. (2019).
[2] In an earlier version of the paper (available here), the authors reported substantially higher estimates, with local fiscal multipliers of 2.4 during the Space Race and 3.8 in the post–Space Race period, respectively.

and 15 OECD countries and employing the local projections approach. Building on this, Ciaffi (2025) extends the analysis to productivity dynamics, showing that public R&D spending exerts a strong and persistent positive effect on labour productivity. At the regional level, Ciaffi et al. (2025) further confirm these results for 243 European NUTS-2 regions, finding that the effects of public R&D are stronger in lagging regions and during deep recessions.

In contrast to this strand of literature, Boysen-Hogrefe (2025) offers a critical reassessment of Deleidi and Mazzucato (2021), arguing that their findings are not robust and exhibit substantial time variation. In light of this debate, the present paper provides new evidence on the macroeconomic effects of government R&D investment and introduces several methodological innovations aimed at enhancing the robustness of the findings. First, it combines two complementary econometric strategies – Structural Vector Autoregressive (SVAR) models and Instrumental-Variable Local Projections (IV-LP) – to test the consistency of the estimated fiscal multipliers. Second, it disaggregates total public R&D into its military and civil (non-military) components, allowing for a direct comparison of their macroeconomic effects on GDP, private R&D, investment, and consumption, thereby shedding light on the transmission mechanisms at work. Third, it applies the sub-sample approach of Blanchard and Perotti (2002) to assess the stability of the multipliers over time. Finally, it incorporates pure shocks from a counterfactual VAR to isolate the exogenous contribution of each public R&D component.

The remainder of the paper is structured as follows. Section 2 summarises recent critiques directed at Deleidi and Mazzucato (2021), providing replies to such critiques as well as addressing further shortcomings identified in Boysen-Hogrefe (2025). Section 3 presents the data and methods, with particular attention to the appropriate procedures used in the fiscal policy literature to compute fiscal multipliers. Sections 4 to 6 present the results from the SVAR, pure-shock, sub-sample, and IV-LP analyses. Section 7 concludes by drawing some policy implications.

2. Discussion of the critiques

In this section, we outline the critiques directed at Deleidi and Mazzucato (2021) and provide our replies, while also addressing additional shortcomings identified in Boysen-Hogrefe (2025). These criticisms can be summarised as follows: i) Deleidi and Mazzucato (2021) invoke the notion of a supermultiplier on the basis that they identify 'big' multipliers, namely, a pronounced response of GDP to government military R&D investment (G_MO); ii) rather than employing price-adjusted variables, they deflate nominal variables using the GDP deflator; iii) instead of estimating an SVAR in levels, they estimate it in first differences; iv) the identification strategy is questionable, since Deleidi and Mazzucato (2021) assume that G_MO is exogenous in the contemporaneous relationship, whereas the results would differ if G_MO were treated as the most endogenous variable – that is, if all shocks had contemporaneous effects on G_MO; v) the estimates are unstable when the model is applied to different sub-samples. Therefore, Boysen-Hogrefe's (2025) conclusions underscore several important considerations. First, he points to the methodological sensitivity of the findings, emphasising that the results depend heavily on the way the data are transformed, particularly in the absence of cointegration. Second, he stresses the problem of temporal instability, as the estimated effects are far from consistent and display significant variation across different periods. The evidence in support of the supermultiplier hypothesis is shown to be strongest in the years 1966–1985, and from 1985 onwards, G_MO appears to have displaced rather than stimulated private R&D, suggesting the presence of crowding-out effects. Third, Boysen-Hogrefe draws a broader policy implication: the impact of public R&D should not be regarded as uniform, but rather as time-varying and contingent on the prevailing historical and institutional environment.

The following discussion addresses the critiques reported above and subsequently considers additional shortcomings highlighted in Boysen-Hogrefe (2025). We begin with the notion of the supermultiplier, which we do not define as a mere 'big multiplier'. In the first part of Deleidi and Mazzucato (2021), a theoretical demand-led framework grounded in the Sraffian Supermultiplier model of growth is developed and illustrated. Originally proposed by Serrano (1995) and Bortis

(1997), and subsequently developed by Cesaratto et al. (2003) as well as Freitas and Serrano (2015) among many others, this model demonstrates the positive relationship between the autonomous non-capacity-creating components of aggregate demand and the level of output, coupled with an investment function endogenously determined by the demand level.[3] The supermultiplier model, therefore, combines the standard Keynesian effect on private consumption with an investment function derived from a flexible accelerator mechanism.[4] Thus, the theoretical definition of the supermultiplier bears no relation to the notion of identifying 'big multipliers'; rather, it constitutes a theoretical concept distinct from the magnitude of our empirical estimates.

Moreover, concerning the estimates and the empirical model, several issues need to be discussed. First, commonly, variables are converted into real terms by using the GDP deflator (see, among others, Blanchard and Perotti, 2002; Ramey and Zubairy, 2018). Different ways to calculate variables in real terms usually do not alter the estimates. For instance, estimates provided by Blanchard and Perotti (2002) using specific deflators or using price-adjusted chain indices do not affect findings. The same conclusion has also been achieved by Boysen-Hogrefe (2025), who shows that the deflation process does not alter the estimates.[5]

Second, the identification strategy proposed by Boysen-Hogrefe (2025) in Appendix 2 is not convincing. The identification strategy required to estimate structural shocks can be implemented either by drawing on extraneous information – for instance, specific properties of the data – or by selectively applying insights from economic theory (Kilian and Lütkepohl, 2017, p. 218). Consequently, the estimation of structural shocks, as well as the resulting coefficients and impulse response functions (IRFs), depends on the identification strategy employed. In the fiscal policy literature, it is common practice to treat government expenditure as exogenous in the

[3] For a recent comprehensive review of supermultiplier models, see Lavoie (2022), Dejuán (2023), and Gallo (2024). For recent empirical analyses, see Girardi and Pariboni (2016) and Barbieri Góes and Deleidi (2022).
[4] The combination of multiplier and accelerator effects is not new in economic theory. The earliest significant contributions were proposed by Samuelson (1939a; 1939b), Kaldor (1940), and Hicks (1950), among others.
[5] In addition, the correlations between the price indexes provided for government expenditure and its components, and the GDP deflator are consistently high, confirming that price movements across categories are closely aligned. The correlations are equal to: 0.78 for total government expenditure; 0.79 for total public R&D; 0.75 for military R&D; and 0.79 for civil R&D.

contemporaneous relationship, that is, unaffected by business cycle fluctuations or other macroeconomic variables. In particular, the assumption of government expenditure being independent of GDP in the present period is justified by the idea that implementation and decision lags prevent fiscal policy from responding contemporaneously to macroeconomic conditions. These lags imply that government spending decisions typically require more than one period to potentially adjust to business cycle fluctuations. Policymakers and legislatures generally need longer than a quarter to observe a GDP shock, decide on appropriate fiscal measures, pass them through the legislative process, and implement them. This consideration is particularly relevant when working with quarterly data. In summary, the fiscal policy literature assumes the absence of automatic effects of economic activity on government expenditure. The issue becomes even more relevant when considering strategic spending, such as public investment and military expenditure, which are typically subject to lengthy bureaucratic and institutional procedures extending beyond a single fiscal year. Public investment decisions, in particular, depend on feasibility studies, project design and planning activities, and approval processes that often involve multiple policy actors as well as public and private institutions, all of which contribute to delaying their implementation. Similarly, military expenditure is driven by political events, strategic considerations, and the safeguarding of national security, and is therefore not directly influenced by business cycle dynamics. Indeed, the literature on military spending treats this category of government expenditure as independent of the business cycle (Auerbach and Gorodnichenko, 2012; Ramey and Zubairy, 2018). In addition, as noted by Deleidi and Mazzucato (2021), military R&D expenditures constitute strategic investments and can thus be considered an exogenous component, since 'allocation decisions were based on assessments by policymakers of the research needs of specific agency missions' (Mowery, 2010, p. 1223). Specifically, changes in military R&D reflect political and military priorities, independent of, for example, GDP or productivity shocks (Mowery, 2012; Moretti et al., 2025). Therefore, estimating an SVAR model with military R&D investment as an endogenous variable may be inherently problematic, as the IRFs are highly sensitive to the chosen identification scheme. Consequently, estimates should be interpreted with caution due to potential limitations in their reliability.

Third, the use of a model specified in first differences was motivated by the fact that the theoretical model presented in Deleidi and Mazzucato (2021) was a model of growth rather than a model solely describing the business cycle. However, we are aware that a VAR model in levels can be estimated and, in some cases, may even be more appropriate than a VAR in first differences. As argued by Kilian and Lütkepohl (2017), estimating a VAR in levels with unit root variables can be done without relying on pre-tests for the cointegration rank, which are themselves subject to errors, or on the assumption of an existing cointegration relationship. In such cases, it is often more appropriate to estimate the VAR without imposing these restrictions, even when unit roots are present. This approach is justified by the fact that the Vector Error Correction Model (VECM) is merely a reparameterization of VAR models in levels. However, it is worth noting that estimating a model in levels with variables that contain unit roots implies assuming that a long-run relationship may exist among them – namely, that government expenditure, and more broadly the components of aggregate demand, may exert persistent effects on GDP. Although this view is not widely shared in the fiscal policy literature, which typically regards government expenditure as influencing only short-run output dynamics, we argue that government expenditure and aggregate demand play a fundamental role in shaping GDP dynamics even in the long-run. Moreover, while much of the fiscal multiplier literature pre-transforms the data to ensure stationarity – either by expressing variables in growth rates (Blanchard and Perotti, 2002; Owyang et al., 2013) or by scaling them by potential GDP (Gordon and Krenn, 2010; Ramey and Zubairy, 2018) – we have generally estimated models both in levels[6] and first differences in several previous studies, analysing the macroeconomic impact of government R&D (De Lipsis et al., 2022; Ciaffi et al., 2024c) and, more broadly, of government spending components (Deleidi, 2022; Ciaffi et al., 2024b). Our findings demonstrate that the resulting

[6] This is also consistent with the models estimated by Blanchard and Perotti (2002), Auerbach and Gorodnichenko (2012), and Antolin-Diaz and Surico (2025).

multipliers associated with government R&D expenditure and the different classes of government spending are robust, regardless of whether the model is estimated in levels or in first differences. In the following sections, we provide several estimates that support our thesis.

Fourth, the sub-sample stability documented by Boysen-Hogrefe (2025) is rarely observed in the fiscal policy literature, and potential structural breaks are difficult to identify through statistical testing. As argued in Kilian and Lütkepohl (2017, p. 655), standard tests typically have low power, particularly when the number or timing of breaks is unknown and may confound persistent transitory dynamics with genuine structural change. Therefore, when detecting structural change is often more appropriate in practice to rely on external economic or institutional information when defining sample periods. This issue is particularly relevant in the context of fiscal policy, which, unlike monetary policy, does not easily lend itself to periodisation based on alternative policy regimes (Blanchard and Perotti, 2002). In addition, the fiscal policy literature typically estimates multipliers using long historical time series. For instance, Antolin-Diaz and Surico (2025) analyse public R&D using a time series of 125 years using variables moving from 1890 to 2015. Their sub-sample stability has been carried out before and after 1948 and excluding the 1940–1945 period. Similarly, Ramey and Zubairy (2018) use the same dataset covering 125 years and examine sub-sample stability by excluding the Second World War years and by restricting the analysis to the post-war period. Blanchard and Perotti (2002) test for sub-sample stability by sequentially dropping one decade at a time over the period 1960–1997. In our new estimates reported in the following sections, we apply the latter method.

Another important shortcoming of Boysen-Hogrefe (2025) concerns the use of IRFs when comparing his findings with ours. The author argues that the IRFs of GDP and R&D would invalidate our results. This interpretation is misleading and is better clarified in Section 3.3, where we distinguish between IRFs, dynamic multipliers, cumulative multipliers, and multipliers derived from pure shocks. Boysen-Hogrefe (2025) reports only IRFs of GDP and R&D, which are elasticities showing percentage variations in response to a fiscal policy shock. Fiscal policy analysis, however, is primarily concerned with multipliers expressed in dollar terms that are usually obtained from IRFs through an *ex-post* transformation. Moreover, caution is warranted even when reporting dynamic multipliers, as they do not adequately account for the dynamics of government spending. Indeed, while spending is typically normalised to one dollar on impact, it generally follows a persistent adjustment path, meaning that an initial shock may accumulate over time and stabilise at a value greater or lower than one. For this reason, cumulative multipliers are more appropriate for fiscal policy analysis (Ramey and Zubairy, 2018). They provide a reliable measure of the impact of discretionary fiscal policy, as they can be interpreted as the dollar change in GDP over time resulting from a one-dollar increase in expenditure (Ramey, 2016). Put differently, the fact that IRFs or dynamic multipliers of GDP may return to zero, or even turn negative after several quarters, does not imply negative cumulative multipliers or the presence of crowding-out effects. Unfortunately, Boysen-Hogrefe (2025) reports only the responses of GDP and R&D in terms of elasticities, which at best would allow for the calculation of dynamic multipliers if the relevant conversion factors were available. However, the computation of cumulative multipliers additionally requires the dynamic responses of the different categories of government spending to fiscal policy shocks, which are not reported in his paper.

Finally, we raise a minor but relevant point regarding the title and presentation adopted by Boysen-Hogrefe (2025). In our assessment, the title does not accurately reflect the scope of the study, as it appears to somewhat overstate the scope of the contribution. Indeed, the paper is not intended to replicate the findings of Deleidi and Mazzucato (2021) but rather to provide further evidence using alternative models and specifications. In fact, only Section 3 is devoted to establishing some comparability with Deleidi and Mazzucato (2021), where Boysen-Hogrefe's IRFs are very similar to Deleidi and Mazzucato's. Moreover, in our view, the paper occasionally employs language and expressions (for instance, in the Title, Abstract, and Highlights) that may convey an overstated impression of its results, which is not fully consistent with the evidence presented or with the criticisms raised.

3. Data and methods

3.1 Data

To detect the effect of generic fiscal policies and those targeted to public R&D on output and business R&D, we use quarterly US data from the BEA covering 1947Q1–2018Q4. The dataset includes real gross domestic product (Y), private non-residential investment (inv), personal consumption expenditures (con), private R&D expenditure (rd) and public R&D components. We break out public R&D into: federal defence R&D ($g\_i\_military$), non-defence public R&D (g_i_civil), and total public R&D ($g\_i\_total = g\_i\_military + g\_i\_civil$). Government consumption expenditure and gross investment (g) is defined net of total public R&D, i.e. overall government consumption and gross investment minus g_i_total.[7]

All nominal series are converted to real terms using the GDP implicit price deflator (2017 base year). Variables enter the empirical analysis in logarithmic levels. Variable definitions and BEA sources are summarised in Table 1, while series are plotted in Figure 1. In Figure 2a, we report the composition of fiscal policy showing the shares of the three components – government consumption and gross investment net of public R&D (g), federal military R&D ($g\_i\_military$), and civil public R&D (g_i_civil) – as proportions of total government expenditure. The yellow and orange segments together constitute total public R&D (g_i_total). Over the sample period, g represents more than 95% of total public expenditure on average, with the two R&D components together making up the remaining share. Furthermore, when examining the allocations of R&D spending, Figure 2b shows that military R&D ($g\_i\_military$) initially accounted for the vast majority of public R&D – exceeding 80% in the 1950s and 1960s – but has gradually declined over time. Conversely, civil R&D (g_i_civil) has steadily increased and, since the 1990s, has become the dominant component. In the recent years, g_i_civil has accounted for around 60% of total public R&D.

[7] In the specifications below, g is included as a standard macro control while the public R&D components ($g\_i\_military$, g_i_civil, and g_i_total) enter separately to identify their effects.

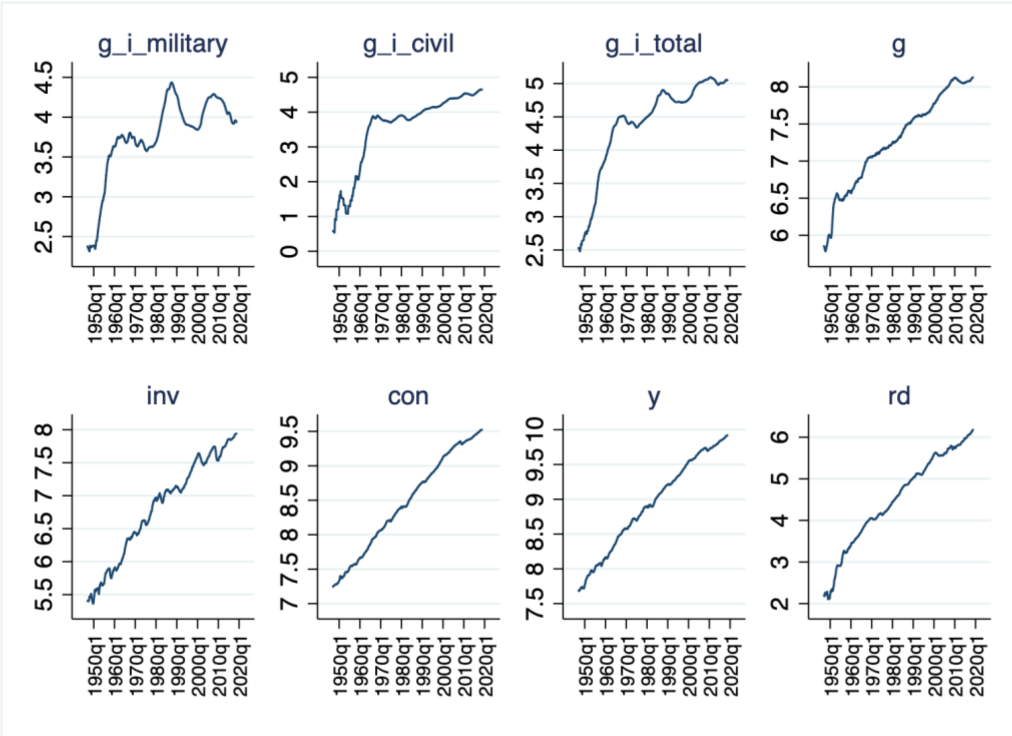

Figure 1. Plot of the variables. Variables are expressed in log-levels (1947Q1-2018Q4).

(a) **(b)**

Figure 2. Figure 2 (a) Share of public expenditure components (1947Q1-2018Q4). Figure 2 (b) Share of public R&D expenditure components (1947Q1-2018Q4).

Data	Description
$g\_i\_military$	Federal defence gross investment in research and development. Billions of dollars deflated with GDP deflator
g_i_civil	State and local, and federal non-defence gross investment in research and development. Billions of dollars deflated with GDP deflator
g_i_total	Total government expenditure in research and development. ($g\_i\_military$ + g_i_civil). Billions of dollars deflated with GDP deflator
g	Government consumption expenditure and gross investment (Net of Total government expenditure in research and development). Billions of dollars deflated with GDP deflator
inv	Gross private domestic investment, Non-residential Investment. Billions of dollars deflated with GDP deflator
con	Personal consumption expenditures. Billions of dollars deflated with GDP deflator
rd	Private research and development (R&D) expenditure. Billions of dollars deflated with GDP deflator
y	Gross Domestic Product. Billions of dollars deflated with GDP deflator

Table 1. Variables and Description. Sources: Bureau of Economic Analysis.

3.2 Methods

SVAR methodology is used to estimate the effect of g_i_total, $g\_i\_military$, and g_i_civil on different macroeconomic variables. An SVAR in levels is represented as follows in equation (1):

$$B_0 y_t = a + \sum_{i=1}^{p} B_i \, y_{t-p} + w_t \ (1)$$

Where $u_t = B_0^{-1} w_t$. B_0 represents the matrix of contemporaneous relationships, and w_t is the vector of exogenous structural shocks. To isolate an exogenous fiscal policy shock, we impose short-run zero restrictions on the B_0 matrix, which are derived from economic theory. We estimate two models with six lags and excluding a deterministic linear trend.[8] In Model 1, we evaluate the macroeconomic impacts of total public R&D (g_i_total), while in Model 2, we separately identify the effects of its components, namely military ($g\_i\_military$) and civil (g_i_civil) R&D. Following

[8] To maintain consistency with Deleidi and Mazzucato (2021), since the VAR was estimated with five lags in first differences, the corresponding model in levels is estimated with six lags. This adjustment accounts for the effective loss of one lag when differencing the data. While some studies include a deterministic linear trend in level specifications, our baseline model does not. Nonetheless, alternative specifications with five lags and a linear trend tend to improve the statistical significance of the IRFs by narrowing their confidence intervals and enhancing their persistence, especially for military R&D expenditure. The corresponding results are available upon request.

Deleidi and Mazzucato (2021), two alternative identification strategies are imposed on Models 1 and 2:

$$\textbf{Model 1}: B_0 y_t = \begin{bmatrix} - & 0 & 0 & 0 \\ - & - & 0 & 0 \\ - & - & - & 0 \\ - & - & - & - \end{bmatrix} \begin{bmatrix} g\_i\_total_t \\ g_t \\ rd_t \\ y_t \end{bmatrix}$$

$$\textbf{Model 2}: B_0 y_t = \begin{bmatrix} - & 0 & 0 & 0 & 0 \\ - & - & 0 & 0 & 0 \\ - & - & - & 0 & 0 \\ - & - & - & - & 0 \\ - & - & - & - & - \end{bmatrix} \begin{bmatrix} g\_i\_military_t \\ g\_i\_civil_t \\ g_t \\ rd_t \\ y_t \end{bmatrix}$$

We follow the standard approach in the fiscal multiplier literature to identify fiscal policy shocks associated with specific components of public spending using short-run zero restrictions (e.g., Blanchard and Perotti, 2002; Auerbach and Gorodnichenko, 2012; Ramey and Zubairy, 2018). With quarterly data, government expenditure is assumed not to respond within the quarter to contemporaneous movements in output, reflecting the idea that implementation and decision lags prevent fiscal policy from responding contemporaneously to macroeconomic conditions. These lags are particularly relevant for strategic expenditure – such as public R&D investment and specifically, military and civil programmes – whose allocation involves feasibility studies, procurement, and multi-stage approvals often extending beyond a fiscal year. When examining public R&D, it is evident that allocations are mission-oriented and independent of business cycle dynamics. Historically, major expansions in public R&D have been driven by scientific and technological competitions with other countries, military rivalry and political priorities, rather than by cyclical economic conditions (Mowery, 2010, 2012; Deleidi and Mazzucato, 2021; Antolin-Díaz and Surico, 2025). Operationally, these assumptions imply a lower-triangular contemporaneous matrix B_0. In Model 1, g_i_total is ordered first, followed by g, rd, and y. In Model 2, we separately identify

R&D components. We adopt an ordering that places $g\_i\_military$, given its mission-driven, security-motivated nature and its widespread treatment in the US as more exogenous, at the quarterly frequency.[9] Once shocks are estimated in models 1 and 2, impulse response functions (IRFs) are calculated. Standard errors are obtained using a parametric bootstrap procedure based on 1,000 replications, and IRFs are reported with one-standard-error bands (corresponding to a 68% confidence interval).[10] Cumulative multipliers are then computed from the estimated IRFs. In addition, when analysing the transmission channels of fiscal policy, private R&D expenditure (rd) is replaced by private consumption (con) and non-residential investment (inv). It is worth noting that while structural shocks associated with public R&D investment (both military and civil) might at first appear to represent technological shocks, they should more appropriately be classified as demand shocks.[11] Public R&D constitutes a component of government expenditure and, consequently, of aggregate demand, reflecting the purchase of goods and services by the public administration. Importantly, however, this classification does not imply that such expenditure lacks supply-side effects. Indeed, public R&D investment generates long-run effects on GDP by stimulating private investment and capital accumulation through the accelerator mechanism, as well as by enhancing labour productivity and varying the capital–output ratio once technological progress has diffused throughout the economy. Finally, it should also be emphasised that public R&D, unlike standard

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[9] Results are unchanged when i) the two R&D components are reversed *g_i_civil* before *g_i_military*, and ii) a block-recursive scheme is used in which *g_i_military* and *g_i_civil* are jointly both treated as exogenous in the contemporaneous relation. The impulse responses and cumulative multipliers are virtually identical across these alternatives. Consistent with this design, the reduced-form residuals associated with the *g_i_military* and *g_i_civil* equations exhibit a low correlation of -0.17 over the full sample.

[10] The choice of 68% error bands follows standard practice in the empirical literature (Blanchard and Perotti, 2002; Perotti, 2004; Caldara and Kamps, 2017). Moreover, Sims and Zha (1999, footnote 15) argue that one-standard-error intervals should be the norm, as they better capture the relevant uncertainty and avoid the overly wide bands implied by higher confidence levels.

[11] In support of this interpretation, we compared our estimated fiscal shocks with the technological shocks discussed in Ramey (2016). Specifically, we computed the correlations between the fiscal shocks associated with total public R&D spending and its two components (military and civil) and the three technological shocks analysed in Ramey (2016, p. 147) and illustrated in Figure 9: Francis, Owyang, Roush, and Di Cecio (FORD); Fernald's utilisation-adjusted TFP (Fernald); and Justiniano, Primiceri, and Tambalotti (JPT) DSGE TFP. The correlations between Ramey's technological shocks and our fiscal shocks for total public R&D are 0.03, –0.03, and 0.06, respectively. For military R&D shocks, the correlations are –0.09, –0.11, and 0.01, while for civil R&D shocks they are 0.11, 0.06, and 0.04. The correlations are very low and not statistically significant, indicating that the shocks identified in our models cannot be interpreted as technological shocks.

government investment, should be considered a non-capacity-creating component of aggregate demand, since it does not exert an immediate and direct effect on the capital stock (Deleidi and Mazzucato, 2019).

Finally, to ensure the robustness of our results, we conduct a set of robustness checks. First, we employ Local Projections as an alternative to IRFs estimated from the SVAR models. Specifically, we use the structural shocks estimated from the SVAR as instruments within an Instrumental Variable-Local Projections (IV-LP) framework to directly compute fiscal multipliers (Ramey and Zubairy, 2018). This approach has the advantage of estimating cumulative multipliers in a single step, using an instrumental variable (IV) estimation, while avoiding potential biases arising from *ex post* conversion factors based on the sample average of the GDP-to-government-spending ratio.[12] Formally, we estimate the IV-LP specification reported in equation (2):

$$\sum_{j=0}^{h} \frac{y_{t+j} - y_{t-1}}{y_{t-1}} = \gamma_h + m_h \sum_{j=0}^{h} \frac{g_{t+j} - g_{t-1}}{y_{t-1}} + \theta_h \sum_{p=0}^{P} z_{t-p} + u_{t+h}, for\ h = 0,1, \dots H \quad (2)$$

We use the structural shock $\hat{w}_t$ from the SVAR as an instrument for the cumulative government spending term $\sum_{j=0}^{h} \frac{g_{t+j}-g_{t-1}}{y_{t-1}}$. The coefficient m_h provides the cumulative multiplier at the horizon h. This one-step IV procedure delivers standard errors for the cumulative multipliers directly, enabling straightforward statistical inference. Moreover, as emphasised by Ramey and Zubairy (2018), framing the estimation as an IV problem highlights the importance of instrument relevance, an issue we return to in Section 6.

Second, we follow Blanchard and Perotti (2002) and test for sub-sample stability by sequentially dropping one decade at a time from 1947 to 2018. Since fiscal policy – unlike monetary policy – does not easily lend itself to periodisation based on distinct policy regimes, this approach

[12] Unlike the use of the *ex-post* conversion factor, this approach has the shortcoming of assuming a constant fiscal multiplier. Further explanation is provided in Section 3.3.

provides a pragmatic way to assess the stability of our estimates across sub-periods. Third, we estimate cumulative multipliers using pure shocks derived from a counterfactual VAR, the rationale of which is explained and described in detail in the following section.

3.3 Fiscal multiplier estimation

In this section, we discuss three key aspects of fiscal multiplier estimation. First, we explain how multipliers can be derived from elasticities in a log-log specification, highlighting the different assumptions underlying the *ex-post* and *ex-ante* approaches. Second, we highlight the relevance of cumulative multipliers, which account for the persistence of fiscal shocks. Third, we employ a pure-shock approach to properly isolate the effects of specific spending components.

With reference to the calculation of the multiplier from the elasticity, it is important to stress that in a log-log specification, the estimated coefficient corresponds to an elasticity, that is, the percentage change in output relative to a one percent change in government spending. Hence, the estimated coefficient is shown in equation (3):

$$\beta = \frac{\partial \ln(Y)}{\partial \ln(G)} = \frac{\partial \mathrm{Y}}{\partial \mathrm{G}} * \frac{G}{Y} \quad (3)$$

To obtain the fiscal multiplier, $\frac{\partial \mathrm{Y}}{\partial \mathrm{G}} * \frac{G}{Y}$ needs to be multiplied by the ratio of GDP to government spending, namely $\frac{Y}{G}$. In practice, this *ex-post* conversion is usually implemented in empirical studies by computing the ratio as the sample average of observed values for output and government expenditure. This adjustment ensures that the estimated elasticities are expressed as the dollar change in output associated with a one-dollar change in fiscal spending, making them directly interpretable as fiscal multipliers. An alternative is the *ex-ante* procedure, which rescales fiscal policy shocks by the ratio of the selected fiscal variable to the dependent variable at each point in time (Owyang et al., 2013).[13] In this way, changes in fiscal variables are expressed as a percentage of the dependent variable, so that the estimated coefficients directly represent the fiscal multiplier. The *ex-ante* approach avoids the need for an ex-post conversion procedure, which may introduce potential biases due to the high volatility of the observed GDP-to-government-spending ratio (Owyang et al., 2013). However, the *ex-ante* procedure relies on an implicit strong assumption that the multiplier is constant and linear over time, implying that the elasticity is not constant. By contrast, the *ex-post* approach implied by equation (3) assumes a constant elasticity and non-constant multipliers.

Considering the different definitions of the fiscal multiplier, Blanchard and Perotti (2002) define it as the ratio of the output response to the initial government spending shock. This definition yields the so-called dynamic multiplier.[14] While fiscal expenditure is typically normalised to one dollar on impact, its persistent adjustment path implies that the effect of a shock may accumulate over time and stabilise at a value either above or below one. For this reason, more recent contributions emphasise the use of cumulative multipliers, which ‘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, p. 864). The cumulative multiplier is obtained by dividing the cumulative change in the outcome variable of interest ($\Delta y_{i,t+h}$) by the cumulative change in the fiscal expenditure ($\Delta G_{i,t+h}$). Specifically, it can be summarised in equation (4):

$$\beta_{cum}^{h} = \frac{\sum_{h=0}^{n} \Delta Y_{i,t+h}}{\sum_{h=0}^{n} \Delta G_{i,t+h}} \quad (4)$$

However, even cumulative multipliers may present challenges when the focus is on a specific spending component which is also very small compared to other spending components, as in the case

[13] An alternative approach, applied by Ramey and Zubairy (2018) following Gordon and Krenn (2010), divides all variables by potential output. However, this procedure has been questioned because potential GDP is sensitive to cyclical fluctuations (Auerbach and Gorodnichenko, 2017; Coibion et al., 2017).
[14] In addition, the literature has commonly relied on the definition of the peak multiplier that can be defined as the maximum value of $\Delta Y(t+h)/\Delta G(t)$ over the horizon $h = 0, \dots H$.

of public R&D (see, Figure 2). Usually, fiscal packages often allocate resources across different spending components, so that the observed GDP response reflects not only the response to the shock to the targeted spending component, but also adjustments in other expenditure categories. Hence, this becomes particularly relevant when the share of the spending component considered is relatively small compared to other classes constituting government expenditure, and the estimated multipliers may therefore be largely influenced by movements in other government spending components. In such cases, interpreting the estimated effect as solely attributable to public R&D would be misleading. One possible solution would be to scale output responses by the total spending ratio Y/G (Antolin-Diaz and Surico, 2025). However, this would essentially yield the multiplier of aggregate government expenditure determined by a public R&D shock (Perotti, 2004), rather than a multiplier associated with this specific spending component. Our interest, instead, lies exactly in identifying the latter, namely the multiplier of public R&D. To do this, we rely on the concept of pure shocks estimated through a counterfactual VAR. This approach – originally developed in the context of fiscal policy by Perotti (2004) and also employed by Bachmann and Sims (2012) – allows us to isolate the effect of a specific fiscal component while holding other expenditure categories fixed at their baseline paths.[15] In this way, the dynamics of output and other variables reflect only the contribution of the targeted spending component. This allows us to obtain a clean measure of its multiplicative effects, abstracting from endogenous reactions of other government expenditure categories. For instance, focusing on the models under consideration, when analysing the impact of military R&D ($g\_i\_military$) on GDP (y) and its components (rd, inv, and con), we re-estimate the system by blocking the endogenous response of other spending categories, such as civil R&D (g_i_civil) and total government expenditure (g). In practice, this implies treating these components as exogenous at their baseline paths, so that the observed dynamics reflect only the pure contribution of military

[15] Similar procedures have been applied in monetary policy studies (Giuliodori, 2005; Samarina and Nguyen, 2024).

R&D.[16] Comparing the responses of the unrestricted model with those of the pure-shock specification allows us to quantify the specific impact of the targeted item, abstracting from interactions with other categories of fiscal expenditure. Also, when using the pure-shock approach, we calculate cumulative multipliers when using SVAR models. This procedure allows us to interpret the multiplier as a precise measure of how many additional dollars of GDP are generated by each additional dollar of a specific R&D spending component, without the risk of attributing effects arising from other categories of government expenditure.

4. Findings from standard and counterfactual VAR models

In this section, we report findings concerning the IRFs and cumulative multipliers calculated through the benchmark SVAR models and counterfactual VARs. Figure 3 displays the IRFs estimated from the benchmark SVAR using total public R&D, and broken down by its military and civil components. The responses indicate that public R&D produces a large and persistent effect on GDP and private spending components, showing a positive reaction of private investment (both R&D and non-residential) and private consumption. The responses to a military R&D shock are less persistent than total R&D. Indeed, the output and investment effects build quickly but gradually fade, approaching zero after roughly 20 quarters. By contrast, civil R&D produces a more persistent impact on GDP and private spending components. However, as argued in previous sections, IRFs and dynamic multipliers are not sufficient to evaluate the impact of a fiscal policy because they do not properly consider the dynamics of government spending responses. Therefore, it is necessary to estimate cumulative multipliers that allow us to calculate the impact of a discretionary fiscal policy per unit of spending as well as to shed light on the feasible, persistent, and long-run effects of government expenditure. Table 2 reports cumulative multipliers, and, for the sake of simplicity, we discuss the average value computed as the mean multiplier over the 8–year (32–quarter) horizon. Total and civil

[16] As Giuliodori (2005) emphasises, this procedure is equivalent to setting to zero the coefficients associated with the other spending components (g_i_civil and g) in all equations of the estimated model, thereby shutting down their endogenous response to the military R&D ($g\_i\_military$) shock.

R&D are associated with an output cumulative multiplier of 12.32 and 11.54, while military R&D of 5.4. Private R&D, investment, and consumption also respond positively to public R&D spending. The corresponding multipliers are, respectively, 0.45, 3.04, and 7.15 for total public R&D; 0.29, 4.07, and 4.66 for military R&D; and 0.07, 2.39, and 6.43 for civil R&D. Furthermore, cumulative multipliers are positive even 8 years after the initial shock, testifying that an increase in public R&D and its components exerts persistent effects on GDP and its private components. In particular, these findings suggest the existence of a supermultiplier mechanism that combines both the crowding-in responses of private investment through the accelerator mechanism with the positive response of consumption passing through the standard Keynesian multiplier.

Table 2 reports the cumulative multipliers obtained from pure shocks derived from a counterfactual VAR applied to both Model 1 and 2. Pure shocks become particularly relevant when examining categories of government spending that are relatively small compared with other components of public expenditure, as is the case for government R&D (see Figure 2). Pure shocks enable us to isolate the specific contribution of each public R&D component while holding the other categories of public expenditure constant at their baseline paths. This approach identifies the *pure* effect of each spending component by abstracting from the endogenous responses of the other government expenditure categories (see the discussion in Section 3.3).

When focusing on total public R&D, the results remain consistent with those of the baseline SVAR. The cumulative multiplier for GDP averages around 15.3, confirming a strong and persistent aggregate effect, while private R&D, investment, and consumption also respond positively, with patterns similar to those obtained previously. Notable differences emerge when comparing the military and civil components. Indeed, the GDP multiplier associated with military R&D obtained from pure shocks averages around 11, higher than in the baseline model, whereas the multiplier for civil R&D remains broadly unchanged at about 11.9. As shown in Figure 4, this pattern can be explained by the fact that an increase in military R&D is accompanied by a reduction in civil R&D during the first 16 quarters, likely reflecting a reallocation of resources from civil to military activities rather than an overall expansion of public research spending. Therefore, these findings indicate that controlling for the endogenous co-movements among spending categories refines the interpretation of R&D shocks. Once these interactions are removed, the estimated effects of military and civil R&D become broadly comparable, with both displaying average cumulative multipliers in the range of 11–12. This evidence suggests that the differences observed in the baseline specification are primarily driven by reallocation dynamics across spending categories, rather than by structural differences in the underlying nature of the two R&D components.

In summary, our findings indicate that an expansion of aggregate demand induced by public R&D investment and its components leads to a persistent increase in GDP through a supermultiplier mechanism. This effect results from the interaction between the standard multiplier effect on consumption and the accelerator mechanism, which allows private investment to respond positively to demand shocks. The relatively high GDP multipliers observed can be explained by the transmission channels of fiscal policy. Specifically, an increase in public R&D spending generates a strong immediate impact on private investment due to the implementation of government research programmes, which require interactions between public and private actors. This, in turn, triggers the standard Keynesian income-generation process, which further reinforces GDP expansion and stimulates additional investment through the accelerator effect. Finally, the analysis based on pure shocks broadly confirms findings obtained through benchmark SVAR models – particularly regarding the magnitude of the multipliers – and demonstrates that there are no substantial differences in the macroeconomic impacts of military and civil R&D spending.

Total R&D | **Military R&D** | **Civil R&D**

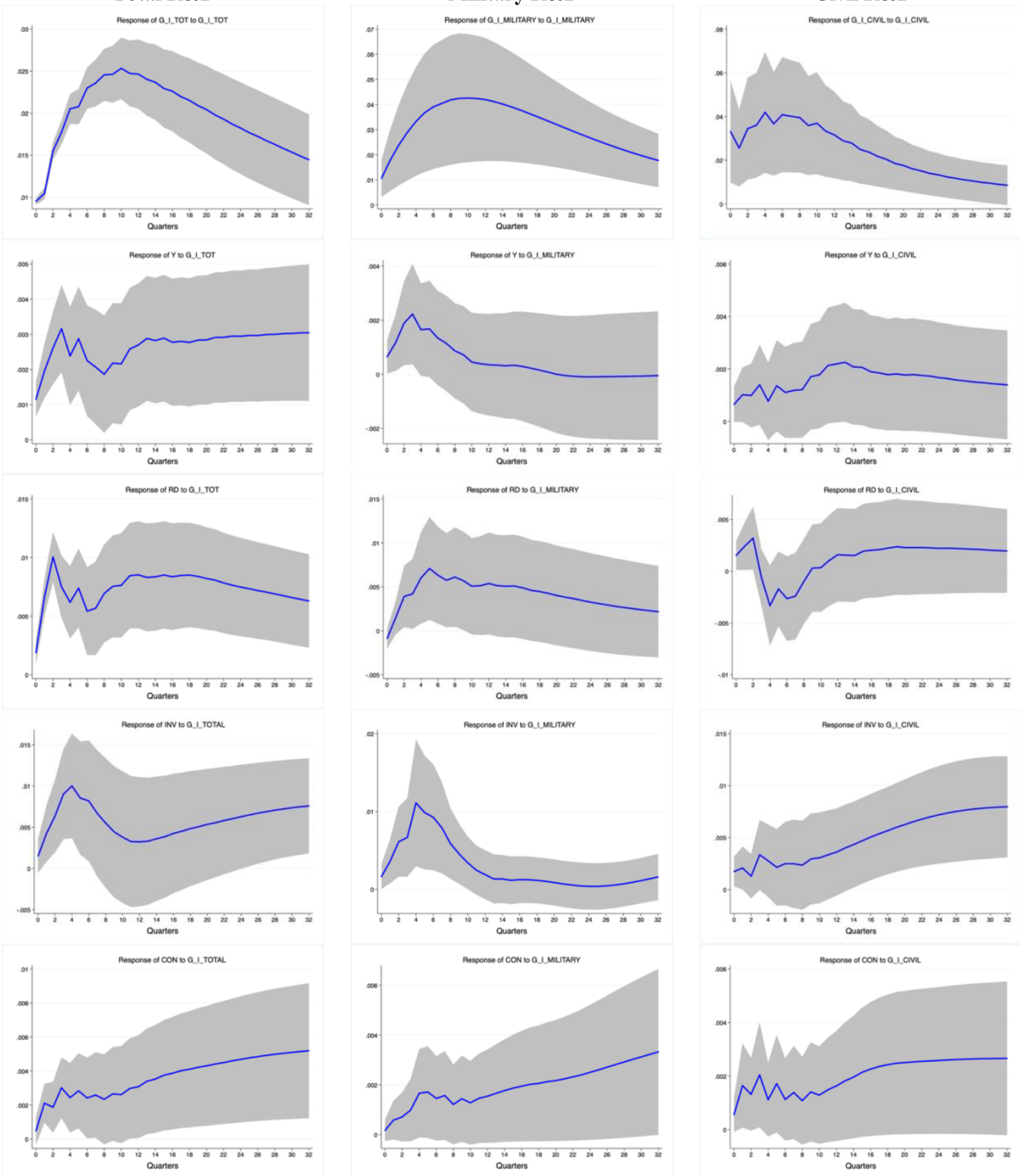

Figure 3. IRFs, SVAR, Model 1 and Model 2, Total R&D, Military R&D and Civil R&D – Full sample.

Military R&D **Civil R&D**

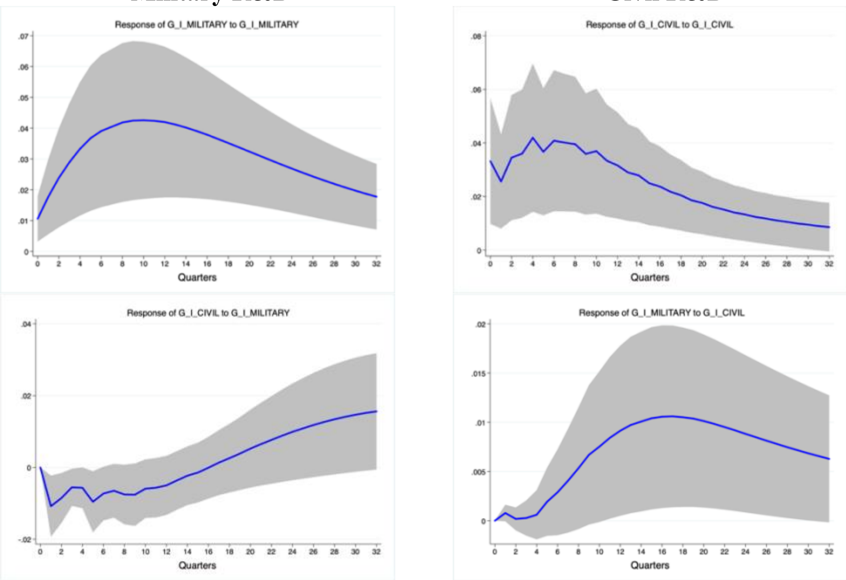

Figure 4. IRFs, SVAR, Model 2, Military R&D and Civil R&D – Full sample.

Total R&D – SVAR Model 1									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	16.08	12.61	10.93	11.07	11.34	11.80	12.36	12.98	12.32
RD	0.62	0.46	0.43	0.44	0.45	0.46	0.47	0.48	0.45
INV	4.47	4.23	3.20	2.69	2.57	2.61	2.75	3.00	3.04
CON	8.23	6.95	6.34	6.62	7.21	7.88	8.59	9.51	7.15
Military R&D – SVAR Model 2									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	12.32	8.56	5.61	3.98	3.06	2.29	1.74	1.36	5.40
RD	0.26	0.41	0.39	0.38	0.37	0.36	0.36	0.35	0.29
INV	5.69	6.67	5.17	3.99	3.33	2.89	2.61	2.50	4.07
CON	3.63	4.59	4.23	4.41	4.82	5.34	6.03	6.89	4.66
Civil R&D – SVAR Model 2									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	8.39	7.85	9.42	11.66	13.21	14.72	16.07	17.27	11.54
RD	0.14	-0.04	-0.02	0.02	0.06	0.09	0.12	0.14	0.07
INV	1.83	1.68	1.74	2.03	2.45	2.92	3.41	3.88	2.39
CON	6.50	5.36	5.09	5.71	6.69	7.67	8.59	9.45	6.43
Total R&D – Counterfactual VAR Model 1, Pure shock									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	15.98	12.78	12.05	12.89	14.34	16.37	19.00	22.32	15.27
RD	0.62	0.46	0.41	0.40	0.39	0.40	0.40	0.41	0.42
INV	3.88	3.31	2.62	2.49	2.67	3.03	3.53	4.16	3.06
CON	7.99	6.75	6.36	6.62	7.18	7.96	8.92	10.06	7.21
Military R&D – Counterfactual VAR Model 2, Pure shock									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	14.52	11.68	9.78	9.37	9.59	10.24	11.28	12.71	10.98
RD	0.26	0.28	0.26	0.24	0.24	0.24	0.25	0.26	0.19
INV	6.26	8.47	8.16	8.06	8.18	8.50	9.10	10.01	7.75
CON	4.23	4.72	4.23	4.43	5.05	5.97	7.14	8.58	5.04
Civil R&D – Counterfactual VAR Model 2, Pure shock									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	6.26	6.34	8.54	11.01	13.50	16.15	19.03	22.15	11.93
RD	0.15	-0.02	-0.06	-0.07	-0.07	-0.07	-0.08	-0.08	-0.02
INV	-0.01	-1.53	-1.30	-0.19	1.12	2.40	3.60	4.70	1.12
CON	5.99	4.87	4.77	4.98	5.37	5.93	6.63	7.45	5.40

Table 2. Cumulative multipliers for Total R&D, Military R&D, and Civil R&D, SVAR and Counterfactual VAR models, Models 1 and 2 – Full sample.

5. Subsample stability, Multipliers, and Pure shocks

Following Blanchard and Perotti (2002), we test for sub-sample stability by sequentially dropping one decade at a time from 1947 to 2018. As they note, fiscal policy – unlike monetary policy – does not easily lend itself to periodisation based on distinct policy regimes; consequently, this rolling-decade approach provides a pragmatic way to assess the robustness of the estimated multipliers over time. All findings obtained for subsamples are reported in Appendix A, while average cumulative multipliers obtained from SVAR models and pure shocks derived from a counterfactual VAR are reported in Table 3.

The cumulative multipliers for total public R&D remain positive across all sub-samples, though some variation in magnitude is observed. The average GDP multiplier ranges between 8.7 and 16.1, with most estimates clustering between 13 and 15, indicating a stable and persistent effect of public R&D on output throughout the post-war period. For military R&D, the cumulative multipliers obtained from benchmark SVAR models are positive and broadly stable, ranging between 3 and 9. Civil R&D contributes steadily to the level of GDP, with multipliers typically between 5 and 18, and higher estimates when the early post–World War II decades are excluded. These results suggest that the expansionary impact of public R&D and its components remains robust across sub-samples. Consistent with the evidence discussed in Section 4, civil R&D tends to generate larger and more persistent effects on GDP than military R&D within the benchmark SVAR.[17] The magnitude of the multipliers remains relatively stable across decades, with some variation observed when excluding the early post–World War II decades.

Once pure shocks are used, the estimated responses of military and civil R&D become more closely aligned. The corresponding multipliers range between 10 and 18 across sub-samples,

[17] For comparison with the sub-sample periodisation adopted by Boysen-Hogrefe (2025), we repeated our estimation over his three historical intervals. The resulting average cumulative multipliers are as follows: for 1947–1966, Total R&D = 13.80, Military R&D = 8.33, and Civil R&D = 71.25; for 1967–1984, Total R&D = 43.14, Military R&D = 13.55, and Civil R&D = 74.96; and for 1985–2018, Total R&D = 19.85, Military R&D = 8.70, and Civil R&D = 96.05. Although the periodisation proposed by Boysen-Hogrefe (2025) is not convincing for the reasons outlined above, the results nonetheless confirm that, despite his IRFs approaching zero or even turning negative, the cumulative multipliers remain positive. This indicates that the expansionary effects of public R&D persist and remain broadly consistent across all historical periods.

converging toward 13–17 in most cases during the more recent decades. Moreover, the GDP response to total public R&D remains strong, with average multipliers ranging between 15 and 18, similar to those obtained in the benchmark SVAR. Higher estimates for total and civil R&D are found when excluding the early post–World War II decades from the sample.

	Benchmark SVAR			***Counterfactual VAR Pure shock***		
	Total R&D – Model 1	*Military R&D – Model 2*	*Civil R&D – Model 2*	*Total R&D – Model 1*	*Military R&D – Model 2*	*Civil R&D – Model 2*
Excl. 47-59						
Y	15.64	3.01	35.25	15.27	21.79	47.86
RD	0.25	0.06	0.56	0.42	0.56	1.01
INV	1.50	1.44	6.03	3.06	10.25	10.66
CON	13.01	2.48	30.81	7.21	11.52	28.94
Excl. 60-70						
Y	8.72	9.10	5.13	30.03	16.72	3.53
RD	0.45	0.28	-0.29	0.70	0.19	-0.34
INV	4.86	4.38	4.18	7.79	8.43	2.06
CON	7.25	6.41	3.92	18.30	7.83	2.02
Excl. 70-80						
Y	11.56	7.72	5.91	10.12	16.56	10.79
RD	0.39	0.26	0.01	0.42	-0.01	-0.07
INV	2.75	3.68	1.31	3.92	7.41	0.31
CON	5.41	2.71	4.25	7.24	6.30	3.35
Excl. 80-90						
Y	13.47	5.04	16.43	16.96	14.65	18.17
RD	0.51	0.20	0.21	0.33	0.07	0.07
INV	2.41	2.09	2.83	2.89	4.82	3.14
CON	6.60	1.67	7.70	5.88	6.30	7.47
Excl. 90-00						
Y	16.06	7.94	18.40	17.22	13.98	17.08
RD	0.53	0.40	0.19	0.48	0.31	0.05
INV	2.97	3.84	2.50	2.12	7.77	0.93
CON	7.33	4.75	6.64	6.42	5.46	5.76
Excl. 00-10						
Y	14.31	5.49	18.60	18.77	9.42	16.53
RD	0.53	0.38	0.31	0.49	0.28	0.21
INV	2.94	4.45	5.73	2.81	8.45	3.27
CON	7.52	3.62	8.77	7.31	3.53	8.22
Excl. 08-18						
Y	13.16	5.17	18.69	15.51	10.36	17.29
RD	0.43	0.32	0.30	0.49	0.24	0.08
INV	2.95	4.16	5.74	3.39	7.02	1.58
CON	6.22	1.72	8.15	7.48	1.32	7.59

Table 3. Average cumulative multipliers for Total R&D, Military R&D, and Civil R&D, SVAR and Counterfactual VAR models, Models 1 and 2 – Subsample.

When examining the transmission mechanism of fiscal policy, the results confirm the operation of the supermultiplier mechanism. Across all sub-samples, both total public R&D and its military and civil components crowd in private investment and stimulate private consumption. Negative responses are observed only for private R&D following civil R&D shocks, and only when the periods 1960–

1970 and 1970–1980 are excluded. In the case of military R&D, this result is confined to the exclusion of the 1970–1980 decade. These findings, however, should be interpreted with due caution, as private R&D reacts positively to total public R&D spending – that is, to the combined effect of its military and civil components – even when excluding the 1960–1970 and 1970–1980 subperiods.

6. Local Projections, Multipliers, and Pure Shocks

To further test robustness, we complement the SVAR analysis with an alternative estimation strategy based on Instrumental Variable-Local Projections (IV-LP). This approach allows direct estimation of cumulative multipliers while relaxing the dynamic structure imposed by the VAR framework. Following Ramey and Zubairy (2018), the structural shocks obtained from the SVAR are used as instruments in the IV-LP regressions, thereby ensuring a consistent identification of exogenous fiscal innovations. We use both structural shocks obtained from our benchmark SVAR models and pure shocks estimated through a counterfactual VAR.

Since the IV-LP framework explicitly relies on an instrumental-variable first stage, it allows us to directly assess the relevance of the instrument. Although the structural shocks from the SVAR are designed to capture exogenous fiscal innovations, their strength as instruments must still be verified. The usual Staiger–Stock (1997) rule of thumb – that F-statistics below 10 indicate weak instruments – may be insufficient in the presence of serial correlation. Following Ramey and Zubairy (2018), we therefore report the effective F-statistics of Olea and Pflueger (2013) and compare them with their corresponding critical values.[18] Figure B1 in Appendix B shows that the effective F-statistics generally exceed the Olea–Pflueger critical thresholds across horizons for public R&D, military R&D, and civil R&D spending, thereby supporting the relevance of the instrument.

The IRFs, which in this case directly represent cumulative multipliers and are reported in Figure 5, confirm SVAR results, showing positive and persistent effects of public R&D on GDP up to eight

[18] The Olea–Pflueger (2013) weak-instrument critical values for one instrument are 23.1 at the 5 percent level and 19.7 at the 10 percent level.

years after the initial shocks. Findings reported in Table 4 show that total public R&D multipliers average between 11 and 13 over the full sample. Responses of private R&D, non-residential investment, and consumption remain positive, suggesting that public R&D continues to crowd in private activity, consistent with the supermultiplier theory. When the analysis is disaggregated by the two R&D components, the IV-LP results reveal average GDP multipliers of about 7 for military R&D and around 9 for civil R&D, indicating that both types of spending exert significant and persistent expansionary effects. When pure shocks are applied, the magnitudes remain broadly similar, with cumulative GDP multipliers around 11 for total R&D, 7.5 for military R&D, and 7 for civil R&D. The analysis of transmission channels shows that both military and civil R&D stimulate private investment and consumption.

The IV-LP reinforce the evidence from the SVAR analysis, confirming that public R&D spending – whether military or civil – plays a key role in boosting economic activity. The consistency of these estimates across different models reinforces the evidence for a positive fiscal multiplier associated with public R&D and highlights that the transmission of R&D shocks operates through the joint action of the Keynesian multiplier and the accelerator effect. Importantly, the macroeconomic impacts of military and civil R&D are broadly similar, indicating no substantial differences in their aggregate effects.

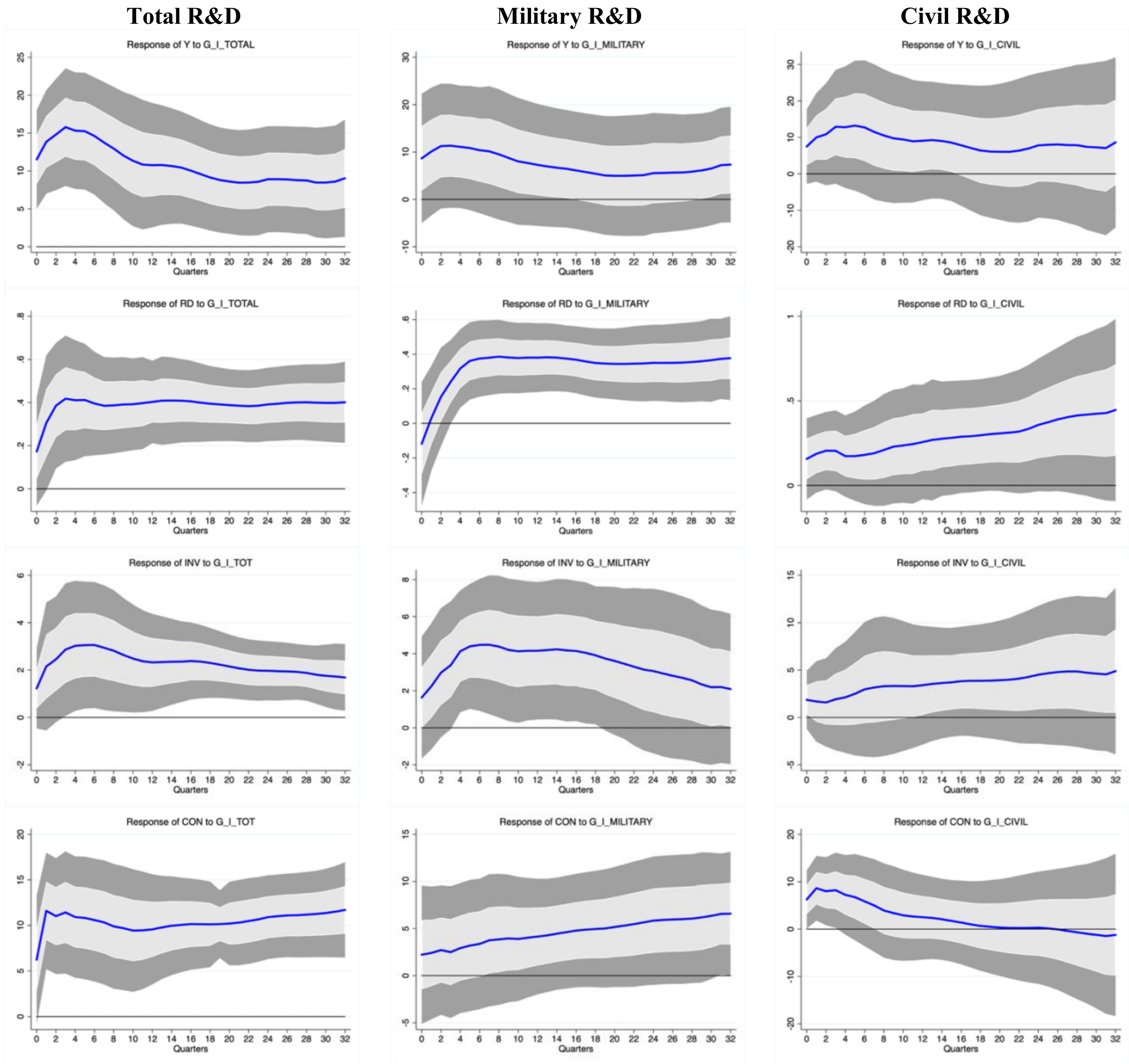

Figure 5. IRFs, IV- LP cumulative multipliers, Model 1 and Model 2, Total R&D, Military R&D and Civil R&D – Full sample.

	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Total R&D – IV-LP									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	15.79	13.74	10.84	10.45	8.81	8.58	8.78	8.60	10.79
RD	0.49	0.39	0.40	0.41	0.39	0.39	0.40	0.40	0.38
INV	2.87	2.94	2.37	2.35	2.23	1.98	1.92	1.73	2.18
CON	11.60	11.02	11.43	10.92	10.82	10.59	10.33	9.89	10.10
Military R&D – IV-LP									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	11.33	10.15	7.66	6.46	5.05	5.12	5.67	7.21	7.00
RD	0.24	0.38	0.38	0.38	0.35	0.35	0.35	0.37	0.30
INV	3.37	4.48	4.15	4.18	3.74	3.14	2.70	2.20	3.29
CON	2.50	3.75	4.03	4.62	5.01	5.66	5.99	6.55	4.48
Civil R&D – IV-LP									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	12.90	11.48	8.93	8.55	6.11	6.96	7.90	7.06	8.60
RD	0.20	0.19	0.24	0.28	0.30	0.34	0.40	0.43	0.28
INV	3.69	4.14	3.91	4.36	4.33	4.51	4.98	4.61	4.17
CON	8.21	4.99	2.65	1.73	0.49	0.23	-0.38	-1.46	2.52
Total R&D – IV-LP, Pure shock									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	18.07	13.16	9.98	9.82	7.85	7.49	7.57	7.27	11.07
RD	0.59	0.44	0.43	0.44	0.41	0.39	0.39	0.38	0.43
INV	2.87	2.94	2.37	2.35	2.23	1.98	1.92	1.73	2.18
CON	6.98	6.31	5.78	6.14	6.20	6.52	6.80	7.03	6.17
Military R&D – IV-LP, Pure shock									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	11.33	10.15	7.66	6.46	5.05	5.12	5.67	7.21	7.48
RD	0.24	0.38	0.38	0.38	0.35	0.35	0.35	0.37	0.30
INV	2.94	3.82	3.23	3.25	2.98	2.64	2.40	2.06	2.75
CON	2.52	3.63	3.67	4.12	4.44	5.03	5.36	5.90	4.10
Civil R&D – IV-LP, Pure shock									
	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	10.85	9.43	7.30	7.35	5.54	6.27	6.79	5.31	7.25
RD	0.16	0.11	0.14	0.17	0.19	0.21	0.27	0.28	0.19
INV	2.92	2.77	2.58	3.21	3.33	3.73	4.26	4.01	3.25
CON	7.22	3.90	1.93	1.00	-0.34	-0.94	-2.01	-3.49	1.39

Table 4. Cumulative multipliers for Total R&D, Military R&D and Civil R&D, IV-LP with shocks obtained by SVAR and Counterfactual VAR models, Models 1 and 2 – Full sample.

7. Conclusions and policy implications

This paper has revisited the macroeconomic effects of public R&D investment in the United States over the period 1947–2018. By combining different models – i.e. Structural VARs, pure-shock derived from a counterfactual VAR, and the Instrumental-Variable Local Projections approach – we provide robust and consistent evidence that government R&D spending exerts strong and persistent expansionary effects on economic activity through a supermultiplier mechanism. Across all specifications, total public R&D yields sizeable cumulative GDP multipliers, with private R&D, non-residential investment, and consumption responding positively and persistently, highlighting the crucial role of these policies in sustaining long-run growth. In addition, when distinguishing between military and civil components of public R&D, both types of spending are found to have positive impacts on GDP and private expenditure. Once pure shocks are estimated, the multipliers for military and civil R&D are broadly similar, suggesting that both categories of innovation-related spending have a comparable impact on GDP expansion.

Moreover, the paper contributes to the ongoing debate by clarifying key theoretical and methodological aspects raised in Boysen-Hogrefe (2025). From a theoretical standpoint, the framework adopted in Deleidi and Mazzucato (2021) builds upon the Sraffian Supermultiplier model of growth (Serrano, 1995; Bortis, 1997; Cesaratto et al., 2003; Freitas and Serrano, 2015), which explains growth as driven by autonomous demand components, with investment adjusting endogenously to the level of demand through an accelerator mechanism. Hence, the supermultiplier should not be interpreted as a 'big multiplier', but rather as a theoretical construct capturing the interaction between autonomous demand and output, operating through its effects on private investment (the accelerator) and on consumption (the multiplier). Our evidence supports this perspective, demonstrating that public R&D stimulates private consumption and investment, and consequently output, in a manner consistent with the demand-led Sraffian Supermultiplier model of growth (Deleidi and Mazzucato, 2019).

From a methodological perspective, the analysis clarifies the distinction between IRFs, dynamic multipliers, cumulative multipliers, and those derived from pure shocks – an aspect that Boysen-Hogrefe (2025) did not consider when presenting his estimates in the form of simple elasticities. Specifically, the IRFs of models estimated in log-level measure percentage changes in response to a fiscal shock, whereas fiscal policy analysis requires effects to be expressed in dollars, since fiscal multipliers are defined as the ratio between the change in output and the change in government spending. In addition, while dynamic multipliers derived from IRFs can provide some information concerning dynamic responses of macroeconomic variables, they do not account for the persistence of government spending. Cumulative multipliers, by contrast, measure the cumulative increase in GDP relative to the cumulative increase in government spending, thereby indicating the impact of discretionary fiscal policy per unit of spending. Moreover, by using pure shocks, the analysis isolates the exogenous impact of each spending category, holding other variables constant at their baseline paths. This allows for a clearer evaluation of the distinct contribution of military and civil R&D to output, free from endogenous interactions across government expenditure. Finally, this study also re-examines sub-sample stability, another critique raised by Boysen-Hogrefe (2025). Detecting structural breaks in fiscal VARs is notoriously difficult, as standard tests have low power when the number or timing of breaks is unknown (Kilian and Lütkepohl, 2017). Moreover, fiscal policy – unlike monetary policy – does not easily lend itself to regime-based periodisation (Blanchard and Perotti, 2002). We sequentially exclude one decade at a time from 1947 to 2018 and find that the impact of public R&D and its components is positive on GDP and private expenditure, thus further confirming the existence of a crowding-in mechanism.

Taken together, these clarifications and new findings provide a coherent picture of the macroeconomic role of public R&D, which acts as a consistent and powerful engine of long-term growth while stimulating private-sector activity. Our results, therefore, reinforce and extend the findings of Deleidi and Mazzucato (2021), confirming the validity of the supermultiplier theory and highlighting the role of aggregate demand management policies in explaining key macroeconomic outcomes. Crucially, our findings show that the positive macroeconomic effects of public R&D stem from investments being directed towards research and innovation activities, rather than from the specific government spending– civil or military – being financed. In the US context, this challenges the conventional view that major technological breakthroughs are primarily driven by military research, highlighting that the effectiveness of public R&D lies in its focus on research and development, regardless of whether it is allocated to its military or civil component.

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Appendix A

In this appendix, we report all cumulative multipliers estimated from our benchmark SVAR models (Table A1–A3) and those calculated using Counterfactual VAR models (Table A4–A6).

Total R&D - SVAR									
Excl. 47-59	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	16.84	17.60	16.09	15.17	14.74	14.74	15.10	15.75	15.64
RD	-0.01	0.16	0.26	0.33	0.37	0.40	0.41	0.42	0.25
INV	1.35	2.57	2.35	1.89	1.53	1.28	1.12	1.02	1.50
CON	13.87	12.76	12.26	12.44	12.82	13.26	13.77	14.36	13.01
Excl. 60-70	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	16.38	10.33	7.04	6.72	6.42	6.30	6.34	6.46	8.72
RD	0.82	0.52	0.43	0.40	0.39	0.39	0.39	0.38	0.45
INV	6.92	6.55	5.02	4.29	4.18	4.32	4.61	4.96	4.86
CON	9.18	7.34	6.39	6.62	7.25	7.97	8.78	9.62	7.25
Excl. 70-80	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	17.59	11.54	9.31	9.52	9.84	10.32	10.86	11.42	11.56
RD	0.62	0.39	0.34	0.34	0.36	0.38	0.40	0.42	0.39
INV	4.86	4.07	2.79	2.26	2.15	2.19	2.31	2.47	2.75
CON	8.08	5.61	4.67	4.75	4.94	5.23	5.62	6.06	5.41
Excl. 80-90	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	18.43	13.74	11.56	11.61	11.89	12.44	13.11	13.91	13.47
RD	0.74	0.54	0.49	0.48	0.49	0.49	0.49	0.50	0.51
INV	4.39	3.79	2.52	1.85	1.65	1.72	1.93	2.20	2.41
CON	8.33	6.43	5.69	5.93	6.38	6.92	7.53	8.18	6.60
Excl. 90-00	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	17.22	15.38	14.52	15.36	16.11	17.05	18.07	19.14	16.06
RD	0.68	0.53	0.51	0.52	0.54	0.55	0.57	0.58	0.53
INV	4.40	4.03	3.02	2.60	2.54	2.62	2.77	2.97	2.97
CON	7.71	6.65	6.27	6.83	7.66	8.53	9.42	10.29	7.33
Excl. 00-10	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	16.69	14.36	13.09	13.42	13.82	14.49	15.21	15.98	14.31
RD	0.65	0.54	0.54	0.55	0.55	0.55	0.55	0.56	0.53
INV	4.35	3.98	2.98	2.57	2.51	2.59	2.74	2.94	2.94
CON	8.04	7.04	6.56	7.02	7.76	8.55	9.37	10.19	7.52
Excl. 08-18	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	15.73	13.03	11.72	12.11	12.50	13.12	13.84	14.60	13.16
RD	0.58	0.44	0.41	0.42	0.43	0.45	0.46	0.47	0.43
INV	4.26	4.04	3.14	2.70	2.58	2.60	2.69	2.84	2.95
CON	7.11	5.91	5.36	5.71	6.32	6.99	7.69	8.39	6.22

Table A1. Cumulative multipliers, Total R&D, SVAR model, Model 1 – Subsample analysis.

Military R&D – SVAR									
Excl. 47-59	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	2.33	3.19	3.23	3.12	2.87	2.55	2.19	1.78	3.01
RD	-0.07	0.01	0.05	0.07	0.09	0.10	0.11	0.11	0.06
INV	2.11	3.13	2.59	1.57	0.74	0.19	-0.21	-0.53	1.44
CON	0.24	1.76	2.71	3.39	3.87	4.29	4.67	5.02	2.48
Excl. 60-70	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	19.40	13.36	9.09	6.82	5.45	4.25	3.32	2.55	9.10
RD	0.28	0.48	0.44	0.42	0.40	0.37	0.35	0.33	0.28
INV	6.85	7.68	5.88	4.46	3.53	2.85	2.38	2.12	4.38
CON	6.29	7.34	6.44	6.20	6.39	6.82	7.48	8.40	6.41
Excl. 70-80	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	19.32	11.79	8.22	6.02	4.23	2.48	0.89	-0.56	7.72
RD	0.25	0.44	0.42	0.40	0.38	0.35	0.32	0.30	0.26
INV	5.91	6.72	4.98	3.73	2.95	2.37	1.97	1.76	3.68
CON	3.29	3.89	3.32	3.00	2.65	2.32	2.10	2.00	2.71
Excl. 80-90	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	17.15	10.89	6.12	3.24	1.23	-0.75	-2.42	-3.86	5.04
RD	0.25	0.38	0.31	0.28	0.26	0.24	0.22	0.20	0.20
INV	4.99	5.59	3.33	1.57	0.58	0.04	-0.19	-0.14	2.09
CON	1.73	2.39	1.53	1.55	1.55	1.57	1.85	2.32	1.67
Excl. 90-00	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	12.83	9.92	7.17	6.18	6.07	6.24	6.77	7.52	7.94
RD	0.42	0.55	0.51	0.49	0.47	0.46	0.45	0.44	0.40
INV	5.92	6.60	4.82	3.65	3.05	2.58	2.26	2.12	3.84
CON	2.58	4.20	4.16	4.59	5.16	5.84	6.73	7.83	4.75
Excl. 00-10	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	12.35	8.68	5.50	3.76	2.93	2.34	2.08	1.99	5.49
RD	0.33	0.53	0.53	0.51	0.48	0.45	0.42	0.39	0.38
INV	6.31	7.63	5.81	4.47	3.78	3.12	2.62	2.33	4.45
CON	1.97	3.36	3.21	3.44	3.89	4.40	5.11	6.00	3.62
Excl. 08-18	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	11.64	8.18	5.18	3.55	2.76	2.21	1.96	1.88	5.17
RD	0.29	0.46	0.46	0.44	0.41	0.39	0.36	0.34	0.32
INV	5.88	7.12	5.42	4.17	3.53	2.91	2.44	2.17	4.16
CON	0.35	1.58	1.52	1.69	1.96	2.35	2.91	3.62	1.72

Table A2. Cumulative multipliers, Military R&D, SVAR model, Model 2 – Subsample analysis.

Civil R&D - SVAR									
Excl. 47-59	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	27.13	29.53	30.36	32.79	36.90	42.28	48.34	54.41	35.25
RD	0.04	0.24	0.43	0.61	0.78	0.93	1.06	1.18	0.56
INV	3.17	5.36	6.42	7.08	7.68	8.19	8.55	8.83	6.03
CON	21.75	22.06	24.36	28.78	33.88	39.20	44.89	50.87	30.81
Excl. 60-70	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	6.66	2.74	3.88	5.82	5.97	6.05	5.52	4.53	5.13
RD	-0.09	-0.44	-0.43	-0.40	-0.37	-0.34	-0.32	-0.31	-0.29
INV	3.65	3.38	3.06	3.46	4.28	5.09	5.83	6.43	4.18
CON	4.75	3.18	2.63	3.20	4.04	4.75	5.46	6.13	3.92
Excl. 70-80	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	3.77	-0.34	0.95	3.90	6.33	8.87	11.20	13.24	5.91
RD	0.10	-0.14	-0.15	-0.11	-0.05	0.02	0.10	0.17	0.01
INV	1.75	0.52	0.19	0.46	0.97	1.52	2.07	2.59	1.31
CON	5.75	3.23	2.74	3.21	3.87	4.61	5.40	6.22	4.25
Excl. 80-90	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	11.34	13.12	15.62	17.65	18.83	20.14	21.33	22.51	16.43
RD	0.22	0.11	0.17	0.20	0.23	0.25	0.28	0.30	0.21
INV	2.08	2.36	2.48	2.55	2.86	3.35	3.89	4.39	2.83
CON	7.06	6.58	6.79	7.47	8.43	9.21	9.90	10.62	7.70
Excl. 90-00	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	10.50	11.67	14.63	18.31	21.34	24.59	27.76	30.87	18.40
RD	0.18	0.03	0.08	0.14	0.20	0.26	0.31	0.36	0.19
INV	1.82	1.78	1.94	2.18	2.57	3.05	3.54	4.03	2.50
CON	6.30	5.11	4.94	5.85	7.13	8.30	9.36	10.32	6.64
Excl. 00-10	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	12.23	14.28	16.63	19.40	21.47	23.68	25.73	27.76	18.60
RD	0.29	0.18	0.24	0.29	0.34	0.38	0.41	0.43	0.31
INV	5.65	8.31	9.28	8.74	7.19	5.39	3.92	2.95	5.73
CON	8.58	7.61	7.24	8.06	9.27	10.42	11.52	12.55	8.77
Excl. 08-18	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	12.30	14.36	16.72	19.50	21.58	23.80	25.86	27.90	18.69
RD	0.28	0.17	0.23	0.28	0.33	0.36	0.39	0.42	0.30
INV	5.66	8.32	9.29	8.75	7.21	5.40	3.93	2.96	5.74
CON	7.58	6.86	6.78	7.62	8.81	9.92	10.91	11.80	8.15

Table A3. Cumulative multipliers, Civil R&D, SVAR model, Model 2 – Subsample analysis.

Total R&D – Counterfactual VAR Model 1, Pure shock									
Excl. 47-59	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	15.98	12.78	12.05	12.89	14.34	16.37	19.00	22.32	15.27
RD	0.62	0.46	0.41	0.40	0.39	0.40	0.40	0.41	0.42
INV	3.88	3.31	2.62	2.49	2.67	3.03	3.53	4.16	3.06
CON	7.99	6.75	6.36	6.62	7.18	7.96	8.92	10.06	7.21
Excl. 60-70	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	18.93	23.44	24.95	27.47	31.33	36.45	42.80	50.23	30.03
RD	0.01	0.25	0.45	0.66	0.87	1.11	1.36	1.63	0.70
INV	2.06	4.99	6.43	7.61	9.11	10.94	13.09	15.51	7.79
CON	14.62	14.55	14.98	16.47	18.63	21.31	24.47	28.12	18.30
Excl. 70-80	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	16.13	9.79	7.61	7.55	7.94	8.69	9.77	11.15	10.12
RD	0.81	0.54	0.42	0.37	0.35	0.33	0.32	0.32	0.42
INV	5.82	4.36	3.24	3.01	3.19	3.60	4.20	4.94	3.92
CON	8.82	7.01	6.45	6.61	7.12	7.91	8.94	10.20	7.24
Excl. 80-90	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	17.67	12.12	11.23	12.70	15.11	18.46	22.90	28.78	16.96
RD	0.62	0.39	0.30	0.28	0.27	0.28	0.30	0.32	0.33
INV	4.31	3.30	2.45	2.28	2.42	2.73	3.16	3.68	2.89
CON	7.83	5.34	4.64	4.82	5.28	6.01	7.01	8.26	5.88
Excl. 90-00	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	18.38	13.89	12.83	13.81	15.61	18.19	21.64	26.15	17.22
RD	0.73	0.55	0.48	0.45	0.44	0.43	0.44	0.45	0.48
INV	3.61	2.62	1.68	1.35	1.43	1.74	2.21	2.77	2.12
CON	7.92	5.92	5.37	5.56	6.02	6.69	7.58	8.70	6.42
Excl. 00-10	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	16.93	15.23	15.31	16.74	18.67	21.23	24.48	28.63	18.77
RD	0.68	0.54	0.50	0.48	0.48	0.47	0.47	0.48	0.49
INV	3.71	2.96	2.28	2.21	2.42	2.78	3.25	3.83	2.81
CON	7.46	6.56	6.44	6.90	7.60	8.42	9.37	10.44	7.31
Excl. 08-18	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	16.45	13.96	13.21	13.75	14.78	16.33	18.38	21.01	15.51
RD	0.66	0.57	0.54	0.52	0.49	0.47	0.45	0.43	0.49
INV	4.00	3.60	3.12	3.06	3.21	3.47	3.82	4.27	3.39
CON	7.93	7.18	6.91	7.16	7.66	8.30	9.07	9.98	7.48

Table A4. Cumulative multipliers. Total R&D, Counterfactual VAR models, Model 1 – Subsample analysis.

Military R&D – Counterfactual VAR Model 2, Pure shock									
Excl. 47-59	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	9.64	16.09	19.16	21.88	25.00	28.59	32.68	37.28	21.79
RD	0.01	0.21	0.38	0.54	0.71	0.88	1.06	1.25	0.56
INV	3.86	7.54	9.51	10.70	11.94	13.38	15.03	16.89	10.25
CON	5.32	8.46	10.24	12.17	14.26	16.51	18.90	21.45	11.52
Excl. 60-70	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	21.73	16.79	13.93	13.32	13.80	15.13	17.38	20.78	16.72
RD	0.21	0.29	0.28	0.28	0.28	0.29	0.32	0.35	0.19
INV	8.22	10.02	8.96	8.48	8.42	8.62	9.18	10.18	8.43
CON	8.18	8.16	7.01	6.86	7.38	8.41	9.99	12.17	7.83
Excl. 70-80	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	19.18	14.35	13.62	14.27	15.33	16.90	19.05	21.91	16.56
RD	0.17	0.12	0.07	0.04	0.02	-0.01	-0.04	-0.07	-0.01
INV	6.48	7.87	7.46	7.55	7.80	8.21	8.85	9.72	7.41
CON	5.13	5.15	5.14	5.82	6.66	7.69	8.92	10.34	6.30
Excl. 80-90	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	19.40	16.04	13.63	13.09	13.17	13.58	14.19	14.93	14.65
RD	0.28	0.23	0.15	0.09	0.07	0.06	0.05	0.04	0.07
INV	5.85	7.69	6.81	5.75	4.68	3.78	3.13	2.68	4.82
CON	5.13	5.15	5.14	5.82	6.66	7.69	8.92	10.34	6.30
Excl. 90-00	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	15.18	13.44	12.02	12.28	13.29	14.80	16.79	19.28	13.98
RD	0.43	0.43	0.39	0.35	0.34	0.33	0.32	0.31	0.31
INV	6.96	8.69	8.11	7.92	8.01	8.29	8.79	9.57	7.77
CON	4.39	5.03	4.56	4.84	5.56	6.51	7.63	8.92	5.46
Excl. 00-10	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	14.65	11.67	9.18	8.11	7.69	7.63	7.83	8.24	9.42
RD	0.33	0.43	0.43	0.40	0.36	0.31	0.26	0.21	0.28
INV	7.66	10.30	9.85	9.31	8.89	8.62	8.58	8.82	8.45
CON	3.69	3.98	3.08	2.92	3.28	3.84	4.52	5.32	3.53
Excl. 08-18	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	13.72	10.69	8.92	8.57	8.84	9.56	10.70	12.27	10.36
RD	0.25	0.27	0.26	0.27	0.29	0.31	0.35	0.39	0.24
INV	5.60	7.58	7.45	7.46	7.59	7.83	8.26	8.93	7.02
CON	2.02	2.05	1.26	0.99	1.04	1.25	1.61	2.09	1.32

Table A5. Cumulative multipliers. Military R&D, Counterfactual VAR models, Model 2 – Subsample analysis.

Civil R&D – Counterfactual VAR Model 2, Pure shock									
Excl. 47-59	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	25.66	29.42	32.29	38.29	48.42	62.79	80.78	101.07	47.86
RD	0.07	0.29	0.52	0.79	1.15	1.60	2.14	2.75	1.01
INV	2.59	5.29	6.85	8.85	12.01	16.02	20.56	25.51	10.66
CON	19.66	18.28	19.32	23.22	29.13	36.69	46.01	57.12	28.94
Excl. 60-70	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	2.39	-1.21	0.34	2.16	3.68	5.25	6.93	8.69	3.53
RD	-0.03	-0.36	-0.43	-0.46	-0.48	-0.49	-0.50	-0.51	-0.34
INV	0.82	-1.04	-0.60	0.69	2.18	3.62	4.88	5.95	2.06
CON	3.81	2.54	2.08	1.68	1.52	1.59	1.84	2.21	2.02
Excl. 70-80	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	4.36	0.25	2.75	6.74	11.26	16.36	21.99	28.12	10.79
RD	0.15	-0.10	-0.16	-0.16	-0.15	-0.13	-0.11	-0.09	-0.07
INV	-0.15	-2.60	-2.59	-1.41	0.00	1.40	2.72	3.98	0.31
CON	4.85	1.69	1.23	1.57	2.33	3.53	5.07	6.87	3.35
Excl. 80-90	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	9.02	10.00	13.55	17.31	21.01	24.81	28.74	32.77	18.17
RD	0.21	0.07	0.05	0.05	0.04	0.03	0.03	0.02	0.07
INV	0.28	-0.36	0.70	2.39	4.12	5.58	6.71	7.59	3.14
CON	6.37	5.57	6.14	6.88	7.82	9.02	10.39	11.87	7.47
Excl. 90-00	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	8.30	10.09	13.23	16.44	19.64	23.11	26.90	31.04	17.08
RD	0.17	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.05
INV	-0.35	-2.03	-1.62	-0.34	1.03	2.31	3.49	4.60	0.93
CON	5.93	5.10	5.27	5.63	6.07	6.59	7.19	7.85	5.76
Excl. 00-10	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	10.00	12.21	14.65	16.90	19.02	21.23	23.56	26.03	16.53
RD	0.31	0.22	0.21	0.21	0.19	0.18	0.17	0.16	0.21
INV	1.31	0.70	1.54	2.78	3.91	4.93	5.86	6.71	3.27
CON	8.83	8.76	8.52	8.39	8.51	8.77	9.13	9.55	8.22
Excl. 08-18	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	Average
Y	10.15	12.23	14.76	17.40	19.90	22.47	25.19	28.06	17.29
RD	0.24	0.08	0.05	0.04	0.03	0.03	0.03	0.03	0.08
INV	0.09	-1.12	-0.65	0.53	1.81	3.01	4.13	5.15	1.58
CON	7.66	7.69	7.95	8.05	8.15	8.33	8.57	8.84	7.59

Table A6. Cumulative multipliers. Civil R&D, Counterfactual VAR models, Model 2 – Subsample analysis.

Appendix B

In this appendix, we provide supporting evidence on instrument relevance for the IV-LP estimation. Figure B1 plots the effective F-statistics for public R&D, military R&D, and civil R&D spending relative to the Olea–Pflueger (2013) critical thresholds at the 5% and 10% significance levels. Values above zero indicate that the instrument exceeds the weak-instrument thresholds across horizons.

(a) (b)

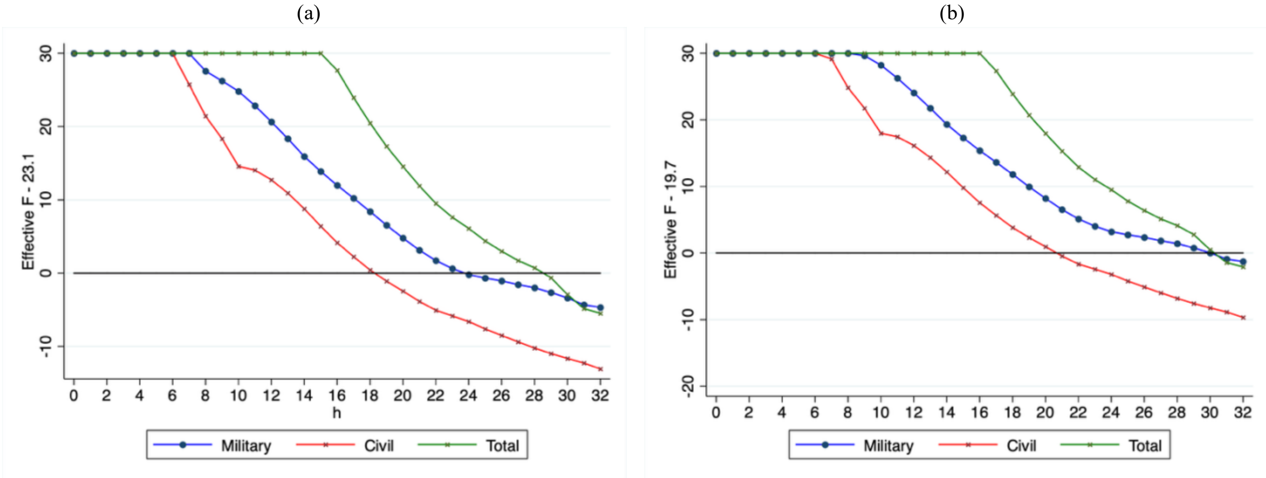

Figure B1. Effective F-statistics relative to Olea–Pflueger thresholds. Notes: Panel (a) plots the effective F-statistics net of the 5% Olea–Pflueger critical value (23.1), while panel (b) reports the corresponding values net of the 10% threshold (19.7). Results are shown for public R&D, military R&D, and civil R&D.

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