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# Public R&D investment in economic crises[☆]

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ABSTRACT

We study the cyclicality of public R&D in 29 OECD countries over the period 1995 to 2019. Public R&D is procyclical on average, and mostly driven by adjustments in public R&D aimed at the government and higher education sectors. However, public R&D reacts asymmetrically over different phases of the business cycle, becoming acyclical during recessions. This acyclicality masks an important heterogeneity across countries: the world's leading innovators behave countercyclically during recessions and even increase public R&D. These results suggest that countries behind the innovation frontier could still strengthen their resilience to economic crises by adopting countercyclical public R&D strategies, thereby also safeguarding long-term growth through innovation.

## 1. Introduction

R&D, as a key component of innovation, is the main driver of long-term economic growth (Aghion and Howitt, 1992, 2009; Mohnen and Hall, 2013; Pavitt, 2001; Romer, 1986). However, R&D, especially in its more basic forms, is subject to market failures (Arrow, 1962; Nelson, 1959). Therefore, policymakers around the world use a variety of public policies to stimulate investment in R&D and innovation and set targets for the R&D-to-GDP ratio (e.g. Bloom et al., 2019).[1]

During economic crises, many businesses reduce private R&D spending.[2] An important driver of this pattern is shrinking demand, as business spending on R&D is predominantly financed out of cash flow (Rafferty and Funk, 2004, 2008). Another explanation is that firms postpone investment decisions in times of high uncertainty (Bloom, 2007). In order to safeguard long-term growth prospects, crises thus challenge governments to set policies that compensate for faltering private R&D spending (Rafferty, 2003). However, crises impose constraints on governments themselves, as tax income declines and pressure for fiscal consolidation builds, leading governments to potentially cut public R&D spending (Kim, 2014).

This paper conducts an empirical investigation of the cyclicality of public R&D. In particular, we ask which of the opposing forces is stronger in a recession: do governments respond more strongly to the need to increase public R&D spending, or to the need for budgetary austerity? We answer this question by studying the cyclicality of public R&D spending among OECD countries, with a particular focus on how public R&D reacts to economic crises and on international

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[1] For example, during the period under review, the Europe-wide growth strategy "Europe 2020" sets a 3 percent ratio of R&D to GDP as one of the five key targets to be achieved by 2020 (European Commission, 2010). The US targets a ratio of more than 3 percent in its "A Strategy for American Innovation" (White House, 2015), while China has committed to raising R&D spending to 2.5 percent of GDP by 2020 in its "Medium- to Long-Term Plan for the Development of Science and Technology" (Cao et al., 2006).

[2] Studies on the cyclicality of business spending on R&D include Aghion et al. (2010), Barlevy (2007), Censolo and Colombo (2019), Comin and Gertler (2006), Fabrizio and Tsolmon (2014), Fatas (2000), Paunov (2012), and Wälde and Woitek (2004), and conclude that business spending on R&D is generally procyclical. It is also argued that firms might invest countercyclically in R&D because recessions lower the opportunity cost of R&D. This is the case for financially unconstrained firms, which tend to invest in R&D countercyclically (Aghion et al., 2010, 2012; Bovha Padilla et al., 2009; López-García et al., 2013).

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heterogeneity along innovation countries' innovation performance. We thereby contribute to the few studies that have considered the cyclicality of public R&D, that have either taken a different view in terms of research question (e.g. Kim, 2014, focusing on different regimes of political economy), or have described government responses to the 2008/09 Great Recession (e.g. Archibugi et al., 2020; Izsak et al., 2013; Makkonen, 2013; Ulnicane, 2016; Veugelers, 2014).

Compared to these studies, we take a broader perspective to study econometrically the cyclicality of public R&D spending over a 25-year period, with a special interest in how public R&D reacts to economic crises. Our analysis, which is based on the Main Science and Technology Indicators (MSTI) database, considers 29 OECD countries from 1995 to 2019. We use two indicators of public R&D that reflect ex-ante and ex-post spending: government budget appropriations for R&D (GBARD) and government-financed R&D expenditures, respectively.[3] The latter measure, based on surveys of the units that carry out R&D, represents actual (ex-post) expenditures. GBARD includes all government R&D provisions in central or federal government budgets. Unlike government-financed R&D, GBARD is not distorted by short-term economic fluctuations, as it represents government priorities at the time the budget was set. At the same time, it might diverge from actual expenditures, as it reflects ex-ante government intentions.

We contribute to understanding the cyclicality of public R&D spending. We begin by estimating the cyclicality of public R&D expenditures by relating them to real GDP growth, and find it to be procyclical. We show that this procyclicality is mainly driven by public R&D spending to be performed in the government and higher education sectors, while spending to be performed in the business sector is on average acyclical.

However, this general procyclicality hides important heterogeneity. First, government R&D spending is asymmetric over the business cycle. Prior literature has shown asymmetric behavior over the business cycle on the one hand for private R&D (Rafferty, 2003) and on the other hand for general public spending (Alesina et al., 2008).[4] We contribute to this literature on asymmetries in spending behavior by addressing whether the cyclicality of public R&D differs between phases of positive and negative GDP growth as well. In particular, governments might deviate from their generally procyclical behavior in recessions to counterbalance shrinking private R&D.[5] Our results confirm asymmetric responses of public R&D spending to recessions and non-recession periods. Averaged across all countries, public R&D is procyclical outside of recessions and becomes acyclical during recessions. This finding adds an important nuance to the general finding of procyclicality.

Second, we investigate heterogeneous responses to business cycles in general and economic crises in particular. Specifically, we study how countries' innovation performance affects governments' decisions on public R&D spending. We show that, over the whole business cycle, governments in countries that are considered to be innovation leaders set acyclical public R&D policies, whereas public R&D spending in countries that are considered less strong is procyclical. We also combine asymmetric and heterogeneous responses and show that leading innovators pursue an acyclical public R&D strategy outside of recessions, but engage in countercyclical spending during recessions. Non-leading innovators set procyclical spending strategies outside of recessions, which turn acyclical during recessions. This different behavior during recessions may widen the gap between strong and weak innovators and contribute to international differences in economic growth.

The remainder of this paper is structured as follows. Section 2 discusses how public R&D varies over business cycles, particularly economic recessions. Section 3 describes the data and econometric approach of our study. Section 4 presents and discusses the results of our econometric analysis. Finally, Section 5 discusses our findings and presents implications for policy.

## 2. Literature review

Public investment in R&D is an essential component of research policy making, correcting underinvestment by private actors due to the public good characteristics of knowledge to the extent that public and private R&D are substitutes (Arrow, 1962; David et al., 2000; Nelson, 1959). Governments can invest in public R&D through programs that provide additional incentives for firms, such as R&D grants and tax incentives, or by directly investing in public knowledge production capacity, for instance by funding universities and government research laboratories (Bloom et al., 2019; David et al., 2000). Governments thereby foster to safeguard the long-term productivity impacts of basic knowledge (Aghion and Howitt, 1992, 2009; Mohnen and Hall, 2013; Pavitt, 2001; Romer, 1986).

Public R&D investment carries some peculiarities compared to private R&D investment. First, there are many ways in which public R&D investment can manifest, and the effects of public R&D on innovation, growth, and welfare depend on the particular set of policy initiatives used (Bloom et al., 2019). Second, public R&D investment is subject to rigidities that create path dependencies. For instance, many countries carry more stringent personnel policies in the public sector than in the private sector, making it more cumbersome to enlarge or downsize R&D laboratories in the public sector at short notice than in the private sector. While funding programs are not directly affected by personnel policies, they can still be tied to multi-year agreements, or can be of geopolitical relevance, making it less attractive to change them in the short run. As such, it can be expected that the cyclicality of public R&D is lower than that of private R&D. Third, being part of public policy making, they are subject to national budgetary constraints and opportunity costs, and can be thought about as long-term political commitments that can be influenced by short-term political interests (Filippetti and Vezzani, 2022).[6]

There is a strand of literature that studies factors explaining public R&D choices. According to this literature, public R&D spending depends on general factors like the scale of the national economy and trade competitive advantage, but also on specific national characteristics of the National Innovation System (NIS) (e.g. Hammadou et al., 2014; Nelson, 1993). Our paper contributes to this literature by studying the role of the business cycle in public R&D. During economic crises, governments are challenged to respond to decreasing private R&D expenditures (e.g. Aghion et al., 2010). Indeed, public investment in R&D attracted substantial policy attention in the Great Recession of 2008/09 (e.g. European Commission, 2011; OECD, 2009, 2012). Concerning whether governments should increase or decrease public R&D spending during recessions, there are theoretical arguments for both procyclical and countercyclical government spending. The classic Keynesian perspective calls for countercyclical public R&D spending to stabilize the economy when growth slows down (Romer, 1993). Countercyclical R&D spending by governments might also be induced by automatic stabilizers, such as the difficulty of dismissing researchers at public universities and research institutes during a recession. From

[3] The remainder of this study uses both measures as indicators of public R&D expenditures. We refer to public R&D expenditures in situations where the distinction between government-financed R&D and GBARD is not critical.

[4] Similarly, Ouyang (2011) shows that private R&D responds asymmetrically to positive and negative demand shocks. Studying fiscal policy, Alesina et al. (2008) show that budget surplus evolves asymmetrically over recessions and booms.

[5] OECD (2012) and Izsak et al. (2013) report that some countries specifically implemented recovery policies in the wake of the Great Recession in 2008/09 that they had not used before.

[6] For instance, Tornell and Lane (1999) argue, in a more general setting and among countries with weak institutions, that procyclicalities in government spending can be explained by intra-bloc competition to appropriate budget surpluses, called the voracity effect (cf. also Alesina et al., 2008; Lane, 2003).

a neoclassical perspective, the government's reaction should depend on the degree of substitutability of government and private spending (Alesina et al., 2008; Arreaza et al., 1999; Lane, 2003). This implies that public R&D spending should be countercyclical if private R&D spending is procyclical and they are substitutes.

Although this suggests that public R&D spending should be countercyclical, public R&D policies are subject to financial constraints. In recessions, governments face tighter budget constraints due to declining tax income, lower demand for government bonds and lower profits from public enterprises (Kim, 2014). At the same time, they usually face pressure to increase spending on unemployment and social security systems. Therefore, they might cut public R&D expenditures during recessions as part of fiscal consolidation. Kim (2014) argues that R&D spending is presumably the most vulnerable category for budget cuts because governments and populations shorten their time horizons in uncertain economic conditions and focus less on the long term, including long-term R&D investment.

Empirical evidence on the cyclicality of public R&D is still scarce.[7] An exception is Kim (2014), who analyzes the cyclicality of government-financed R&D for the pre-Great Recession period from 1981 to 2008. Based on a political economy perspective, Kim argues that different institutional characteristics, reflected in different regimes of political economy, affect how governments respond to public R&D over the business cycle. Kim shows countercyclicality in coordinated market economies but acyclicality in liberal and mixed market economies.[8] However, Kim's study is focused on these institutional differences and does not present general estimates of the cyclicality of public R&D. In another related study, Censolo and Colombo (2019) investigate heterogenous responses over the business cycle, although they focus on private R&D spending. They estimate the cyclicality of R&D over the period 1999–2014 and find that only 'core' EU countries maintain prolonged countercyclical spending, but not 'periphery' EU countries or recently joined member states.[9] The findings of Censolo and Colombo feature in a broader strand of literature studying the co-evolution of R&D investment across the EU, with a particular focus on the difference between the European core and periphery (e.g., Archibugi and Filippetti, 2011).

A few studies have addressed public R&D during the Great Recession of 2008/09. Makkonen (2013) compares public R&D spending in EU-27 countries just before and after the Great Recession and documents mixed evidence of pro- and countercylical behavior. Izsak et al. (2013) also examine the effect of the 2008 Great Recession on public R&D in EU member states. While they confirm that, in the initial 2008–2010 period, most countries increased or maintained their public R&D spending, some countries found it difficult to maintain funding levels in the following years. They also report a slight movement toward more targeted policies. Others countries tried to make public funding more efficient by reinforcing public–private R&D partnerships.[10] OECD (2012) draws similar conclusions for a larger set of OECD countries, confirming that most of them did not cut their public R&D budgets in 2009, the most severe year of the 2008/09 Great Recession. Case studies on the policy responses in specific European countries confirm these mixed responses. In Germany, public R&D programs were bolstered considerably, especially targeting SME innovation (Brautzsch et al., 2015). In Spain (Cruz-Castro and Sanz-Menéndez, 2016) as well as in Greece (Kastrinos, 2013), the crisis led to severe budget cuts and government reforms.

Overall, the literature has made efforts to describe the evolution of public R&D policy during the Great Recession. However, these results, while important, remain mostly descriptive, especially not offering much explanation for heterogenous findings. Considering the attention that the literature has dedicated to the cyclicality of R&D in the business sector,[11] this is surprising. This paper closes this gap and contributes to a better understanding of the cyclicality of public R&D by providing a systematic analysis of the phenomenon.

With this goal in mind, this paper aims to answer several salient questions. First, we consider the general cyclicality of public R&D. In particular, we investigate whether investment in public R&D in OECD countries generally behaves procyclically or countercyclically. This complements previous work on the impact of the Great Recession on public R&D (e.g. Izsak et al., 2013; Makkonen, 2013; OECD, 2012), or work on the cyclicality of public R&D in different political economy regimes (Kim, 2014), by providing general estimates of the cyclicality of public R&D in an econometric framework. As private investment in R&D generally behaves procyclically (e.g. Aghion et al., 2010), our results on the cyclicality of public investment in R&D is informative of the degree to which governments are compensating for drops in private investment during crises.

Second, previous research has pointed out that private R&D behaves asymmetrically over the business cycle, responding differently to booms and busts (Ouyang, 2011; Rafferty, 2003).[12] We follow this line of research and investigate whether public R&D also evolves differently during recessions than outside of recessions. In doing so, we contributing to understanding whether public R&D adapts during crises by becoming more countercyclical than outside of crises.

Third, we investigate whether, and to what extent, the cyclicality of investment in public R&D is heterogeneous across countries. Previous work has pointed out heterogeneities in cyclicalities according to political regimes and across countries in the EU (Censolo and Colombo, 2019; Kim, 2014). Based on the literature that shows that the National Innovation System (NIS) influences governments' choices on public R&D spending (Hammadou et al., 2014), our study provides an additional explanation for heterogenous public R&D choices over the business cycle: countries' innovation performance. While the NIS approach typically establishes a link between national innovation performance and specific actors, institutions and their interaction in the production of knowledge, we focus directly on the country's innovation performance which we measure by the country's ranking in the Global Innovation Index (Cornell University et al., 2020). In a narrow sense, this analysis extends this literature by investigating whether national innovation performance also affects the cyclicality of public R&D spending. In a broader sense, scholars have also expressed concerns about the differential evolution of innovation-driven growth in the EU (Archibugi et al., 2020). By providing evidence on cross-country heterogeneities in the cyclicality of R&D, we broaden the perspective of intra-European dynamics considered in past studies (Archibugi and Coco, 2005; Censolo and Colombo, 2019), to include other OECD member states, and generalize the insights of case studies through

[7] The empirical literature finds that general public spending is acyclical across the OECD (Abbott and Jones, 2011), with differences between developing and developed countries (Talvi and Végh, 2005) and between countries with higher and lower levels of inequality (Woo, 2009).

[8] Kim's study categorizes the group of coordinated market economies as Austria, Belgium, Denmark, Finland, Germany, Iceland, Japan, the Netherlands, Norway, and Sweden while Australia, Canada, Ireland, New Zealand, the UK and the USA are categorized as liberal market economies.

[9] Censolo and Colombo (2019) consider as core EU countries Belgium, France, Germany, the Netherlands, Denmark, the United Kingdom, Austria, Finland and Sweden. The group of periphery countries includes Italy, Ireland, Greece, Portugal, and Spain, and the group of recent joiners includes the Chech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Bulgaria, and Romania.

[10] We focus on the input side, that is, the effect of the recession on public R&D spending but not on its effectiveness. For an evaluation of the effects of public R&D subsidies during the 2008/09 recession, see Hud and Hussinger (2015).

[11] See footnote 2 for an overview of this literature.

[12] For private R&D, it is argued that R&D falls in recessions because of liquidity constraints which outweigh low opportunity costs while in booms R&D is likewise reduced because of high opportunity costs.

an econometric framework (Brautzsch et al., 2015; Cruz-Castro and Sanz-Menéndez, 2016; Kastrinos, 2013).[13]

## 3. Data and econometric model

Our empirical analysis is based on the MSTI database (version 2022/1) provided by the OECD (2022a). The MSTI database contains information on public R&D expenditures from 1981 onward, but new EU member states provide data only from the mid-1990s onward, and information on government debt levels, an important explanatory variable in our model, is available only beginning in 1995. Hence, we restrict our estimation sample to the period from 1995 to 2019.[14] The sample is an unbalanced panel of 29 countries with an average of 21 yearly observations per country, ranging from 12 to 25 observations. Table 8 in the Appendix provides the list of countries and how often and for which time period each country is observed.

The MSTI database provides two indicators of publicly financed R&D expenditures: Government Budget Appropriations for R&D ($GBARD$) and government-financed R&D ($GovFinRD$). These two measures differ mainly in how they are collected but also differ somewhat in the type of public R&D they capture. Government-financed R&D is collected from surveys of R&D-performing units in all four R&D performing sectors (business enterprise, non-profit organizations, higher education and government). In contrast, GBARD is collected using funder-based budget reporting and includes all government R&D provisions in central (federal), regional (state), and local (municipality) government budgets.[15] As GBARD refers to budget provisions, it measures the amount the governments committed to spend on R&D both inside and outside the government at the time the final budget was set.[16,17] However, governments might deviate from their intended budget plans because of, for instance, unexpected short-term economic fluctuations. The difference between the two indicators could also increase when private R&D performers change their behavior by, for instance, discontinuing certain R&D activities that could reduce the demand for public co-financing or increasing efforts to attract R&D co-financing from the government. Therefore, GBARD reflects ex-ante spending better, while government-financed R&D captures actual (ex-post) spending. The second difference relates to publicly financed R&D activities performed abroad.[18] While they are included in GBARD, government-financed R&D covers only publicly financed domestic R&D activities.

$GBARD$ is directly observed in the data, while $GovFinRD$ is calculated as the reported share of gross domestic expenditure on R&D (GERD) that is financed by the government times GERD. We define two dependent variables each for $GovFinRD$ and $GBARD$. The first set of variables, $ln(GovFinRD)_{it}$ and $ln(GBARD)_{it}$, are the log levels of $GovFinRD$ and $GBARD$ in country $i$ and year $t$, respectively. The second set of variables, $Gr(GovFinRD)_{it}$ and $Gr(GBARD)_{it}$, are the corresponding one-year growth rates.

To determine how public R&D expenditure responds to business cycles, we estimate the following benchmark model:

$$y_{it} = \beta_0 + \beta_1\, y_{it-1} + \beta_2\, Gr(GDP)_{it} + \beta_3\, ln(GDP)_{it-1} + \beta_4\, Surplus_{it-1} + \beta_5\, Debt_{it-1} + \beta_6\, Interest_{it-1} + \alpha_i + \epsilon_{it} \quad (1)$$

Here, $y_{it}$ is either $ln(GBARD)$ or $ln(GovFinRD)$, $\alpha_i$ is a country fixed effect that captures unobserved heterogeneity across countries, and $\epsilon_{it}$ denotes the idiosyncratic error term. Our main variable of interest, that captures the business cycle, is the growth rate of GDP, $Gr(GDP)$. If $\beta_2 > 0$, public R&D expenditure increases with the growth of the economy, indicating procyclicality. If $\beta_2 < 0$, public R&D decreases when the economy grows, indicating countercyclicality. When $\beta_2 = 0$, public R&D is acyclical.

We use a dynamic specification in Eq. (1) and include lagged public R&D spending, $y_{it-1}$, as an additional explanatory variable because many of the public R&D programs for business enterprises are multi-annual programs. Furthermore, a large proportion of government intramural R&D is spent on R&D personnel and cannot be adjusted in the short term. The extent to which governments can finance R&D activities is also influenced by budgetary developments. From a short-run perspective, public R&D spending is likely to depend on the public budget deficit or surplus, as high deficits limit spending on R&D, and in the long run, high levels of public debt exert strong pressure to consolidate fiscal budgets in general, which might also lead to cuts in R&D spending. Higher levels of debt constrain spending because programs that add to the deficit are increasingly difficult to implement and because interest payments consume an increasing share of the government budget (Guellec and Ioannidis, 1997). Hence, we also control for public surplus ($Surplus$), public debt ($Debt$), and long-term interest rates ($Interest$), all of which we lag by one year. Finally, we control for country size by including the lagged level of GDP, $ln(GDP)_{it-1}$. Table 1 provides definitions, units, and data sources for all variables.

As a robustness check, we re-estimate the benchmark model taking tax incentives in public R&D spending as dependent variable. This accounts for the potential worry that OECD countries increasingly make use of R&D tax incentives, as an indirect support measure, to boost business R&D (Appelt et al., 2019) and are doing so to varying degrees. During recessions, R&D tax incentives can behave procyclically because of lower private R&D spending to be claimed. At the same time, governments might provide more generous R&D tax incentive schemes as a countermeasure. Furthermore, R&D tax incentive schemes might allow firms to carry over tax credits to the future, as not to lose benefits during years where taxable income might be lower or even negative. As information on R&D tax incentives is not covered by the MSTI database, we make use of the OECD R&D Tax Incentives database, which collects data on R&D tax incentives but only from 2000 onward (OECD, 2022b). Tax incentives measure any form of tax relief that is provided to companies for private R&D activities as an allowance, exemption, deduction or credit.

Furthermore, we extend the benchmark model (1) in three ways to answer our additional research questions and, as an alternative to specifying the benchmark model in log-levels of public R&D, we specify $y_{it}$ as the growth rate of public R&D, $Gr(GBARD)$ and $Gr(GovFinRD)$, respectively. First, to determine whether governments react asymmetrically to positive and negative GDP growth, we interact the growth rate

[13] Studies of the cyclicality of private R&D have highlighted the importance of liquidity constraints, with financially constrained firms investing in R&D procyclically and unconstrained firms investing countercyclically (Aghion et al., 2012). While studying differential responses based on countries' liquidity constraints is not the main focus of this paper, we control for countries' financial situation in the analysis.

[14] We do not consider the period 2020–2021 to avoid the effects of the COVID-19 pandemic, which are likely not representative of the impact of other (economic) crises. The impact of the COVID-19 pandemic on (public) R&D merits its own analysis as we discuss in the conclusion.

[15] Countries may not include local governments' budgets if their contribution is negligible or if data is not available (Eurostat, 2020). In Europe, only Cyprus, Denmark, Estonia, Ireland, Latvia and the UK include local budgets, which might lead to a slight underestimation for the group of countries that does not include them (Eurostat, 2009).

[16] According to the Frascati Manual, countries can choose between reporting final budget appropriations or actual outlays, but only Hungary (and Bulgaria, which is not included in our final sample) reports actual outlays (Eurostat, 2009).

[17] One of the main virtues of GBARD which results from it being appropriations, is that more recent data is available than is available for $GovFinRD$. However, we do not take advantage of this feature in our analysis to ensure that differences in results for the two indicators are not driven by differences in time periods.

[18] Publicly financed R&D activities performed abroad include government contributions to international R&D programs and supranational organizations.

of GDP, $Gr(GDP)_{it}$, with $Recession$, which is a country-year-specific recession indicator that takes the value of 1 if $Gr(GDP)_{it} < 0$.

Second, we address the heterogeneity in government responses to economic crises by interacting the growth rate of GDP, $Gr(GDP)$, with the country's innovation performance. To measure the country's innovation performance, we use the 2020 edition of the Global Innovation Index (GII) classification of the country's innovation status (Cornell University et al., 2020).[19] We categorize the countries into innovation leaders ($L$, GII 2020 rank 1–10), innovation followers ($F$, GII 2020 rank 11–23), and moderate innovators ($M$, GII 2020 rank 24–100). Table 8 in the Appendix provides the innovation status for each country.[20] As expected, innovation leaders on average place a higher policy priority on R&D than innovation followers, as reflected in a higher ratio of public R&D expenditures to GDP. Innovation followers in turn place a higher priority on R&D than moderate innovators.[21]

Third, we investigate whether governments respond to economic crises with shifts in their allocation of public R&D spending according to beneficiaries. Government-financed R&D can be split by whether the beneficiary is the business sector, government sector, or higher education sector. We estimate model (1) separately for each subgroup.

Table 2 contains basic summary statistics. On average, GDP has been growing at the rate of 2.67 percent per annum. Public R&D growth is of a similar order of magnitude, at about 2.84 percent for $GBARD$ and 2.99 percent for $GovFinRD$. In addition, Table 7 in the Appendix shows correlations between the key variables. As expected, $ln(GovFinRD)$ and $ln(GBARD)$ are strongly correlated with each other and with $ln(GDP)$. $Gr(GDP)$ is positively correlated with $Gr(GovFinRD)$ and $Gr(GBARD)$, but not with their levels.

Fig. 1 plots the growth rate of government-financed R&D expenditures ($Gr(GovFinRD)$) over GDP growth rates ($Gr(GDP)$). To maintain readability, we focus on growth rates smaller than ±10 percentage points. On average, the relationship appears procyclical, with positive growth in government-financed R&D in periods of economic expansion, and negative growth during recessions. A more thorough econometric analysis, including controlling for additional variables, is conducted in the following section.

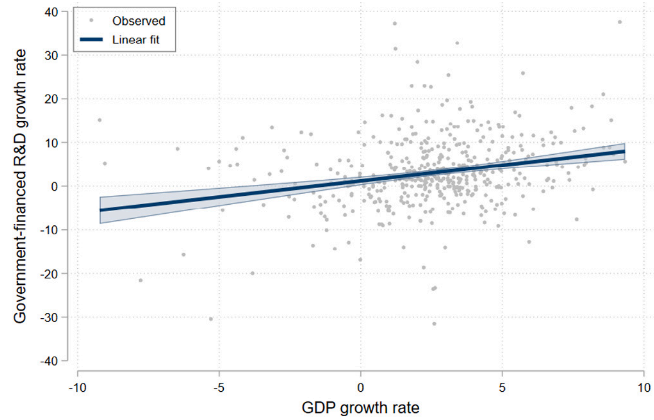


**Fig. 1.** Growth of public R&D by GDP growth. *Notes:* GDP growth rates larger than ±10 percentage points are not included. The blue line shows a linear fit. The areas show 95% confidence intervals. $n = 476$.

## 4. Results

Section 4.1 presents results for our benchmark model on the average cyclicality of public R&D. Section 4.2 presents the core results of the study, investigating asymmetry and heterogeneity in the cyclicality of public R&D responses.

### 4.1. Average cyclicality of public R&D

Table 3 shows the results of our benchmark model (1) using the log-level of our two measures of public R&D, $ln(GovFinRD)$ and $ln(GBARD)$ in models (1) to (7) and the corresponding growth rates in models (8) to (10) as outcome variables. Depending on whether we assume a dynamic specification and/or country fixed effects, the econometric models we use to estimate our benchmark model differ. Model (1) in Table 3 neglects dynamics and country fixed effects and can be estimated with ordinary least squares (OLS); model (2) and (3) both control for country fixed effects, while they differ in the estimation method used (fixed effects (FE) estimator in (2) and first difference (FD) estimator in (3)); models (4) to (7) add dynamics. While model (4) and (6) employ the Arellano and Bond (1991) GMM estimator (A-B) for $ln(GovFinRD)$ and $ln(GBARD)$, respectively; model (5) and (7) use the bias-corrected least-squares dummy variable (LSDVC) estimator proposed by Bruno (2005a,b).

Across these models, the coefficient of interest is that of GDP growth, $Gr(GDP)$. When it is positive, public R&D increases with the growth of the economy, indicating procyclicality, while a negative coefficient indicates countercyclicality. In all specifications (1) through (7), the coefficient of $Gr(GDP)$ can be interpreted as a semi-elasticity. When we do not allow for country fixed effects and dynamics, the coefficient of GDP growth in model (1) (−0.174) is negative but not statistically significant. In model (2), the coefficient of GDP growth reverses, turning positive, but is still insignificant at 0.243. For consistency, the FE estimator requires all explanatory variables to be strictly exogenous, which might be questionable for our main variable of interest $Gr(GDP)$, as it is likely to depend on past levels of public R&D. As an alternative, a less demanding but also less efficient approach to removing country-specific variation is to allow $Gr(GDP)_t$ to depend on the history of public R&D (from $t-2$ onward) through a model in first differences (model (3)). The coefficient of GDP growth becomes larger and statistically significant at 0.451 ($p < 0.05$). After controlling for constant unobserved differences in the log-levels of public R&D between countries, our results therefore indicate on average *procyclical* public R&D investment when estimating it over the full business cycle.[22] Procyclicality holds across the remaining specifications, at different levels of statistical significance. Finally, in our preferred specifications for log-levels, we also account for dynamics in public R&D expenditures in models (4) to (7). While the A-B estimator provides asymptotically unbiased estimates in dynamic panels, it does not correct for biases induced by a small $N$. Since our country panel is naturally characterized by small $N$, we prefer estimating the dynamic model using the LSDVC estimator which does correct for a potential finite sample bias. One downside to this approach is that the LSDVC estimator requires strictly

[19] The GII is provided by the World Intellectual Property Office for about 130 countries. It is based on 80 indicators that capture measures for both innovation input and innovation output. On the input side, the indicators capture human capital and research, institutions, infrastructure, market sophistication, and business sophistication; pillars that are conducive to innovation within an economy. On the output side, indicators take into account the creation, the impact and the diffusion of knowledge, intangible assets and the production of creative goods and services. For more information, see Cornell University et al. (2020, p. 202–208).

[20] The results presented here are robust to minor changes in the cutoff thresholds.

[21] Innovation leaders in the sample spend on average 0.74 percent of GDP on public R&D, innovation followers spend on average 0.60 percent, and moderate innovators 0.40 percent. The difference between innovation leaders and followers, and between followers and moderate innovators, is significant at $p < 0.01$.

[22] In the next sections, we explore heterogeneities and asymmetries in the cyclicality of R&D.

**Table 1**
Variable definitions.

| Variable | Definition | Unit | Source |
|---|---|---|---|
| $ln(GovFinRD)$ | Government-financed gross R&D expenditures, in log. Calculated as the reported share of government-financed GERD times GERD. | Million PPP $[a] | OECD MSTI |
| $ln(GBARD)$ | Government budget appropriations for R&D, in log. | Million PPP $[a] | OECD MSTI |
| $ln(RDTax)$ | Indirect government support through R&D tax incentives, in log. | Million PPP $[a] | OECD R&D Tax Incentives Database $[b] |
| $ln(RDTaxSub)$ | Combined government budget for R&D and tax incentives support for business R&D, in log. | Million PPP $[a] | OECD R&D Tax Incentives Database $[b] |
| $Gr(GovFinRD)$ | Year-over-year natural growth rate of $GovFinRD$ | % | OECD MSTI |
| $Gr(GBARD)$ | Year-over-year natural growth rate of $GBARD$ | % | OECD MSTI |
| $Gr(RDTax)$ | Year-over-year natural growth rate of $RDTax$ | % | OECD R&D Tax Incentives Database $[b] |
| $Gr(RDTaxSub)$ | Year-over-year natural growth rate of $RDTaxSub$ | % | OECD R&D Tax Incentives Database $[b] |
| $GDP$ | Gross Domestic Product | Million PPP $[a] | OECD[c] |
| $Gr(GDP)$ | Year-over-year natural growth rate of $GDP$ | % | OECD MSTI |
| $Recession$ | Country-specific recession period indicator: 1 if $Gr(GDP) < 0$, 0 otherwise. | 0/1 | OECD MSTI |
| $Surplus$ | Government budget surplus | % of $GDP$ | OECD[c] |
| $Debt$ | Government debt | % of $GDP$ | OECD[c] |
| $Interest$ | Long-term interest rate | % per annum | OECD[c] |
| $L, F, M$ | Country's innovation performance. According to the country's ranking in the 2020 Global Innovation Index, we distinguish countries into leading innovators ($L$, rank 1–10), innovation followers ($F$, rank 11–23), and moderate innovators ($M$, rank 23–100). | Categorical | Global Innovation Index[d] |

Notes: Annual data.

[a] All monetary amounts are transformed into inflation and Purchasing Power Parities (PPP) adjusted values. That is, they are measured in million PPP $ in constant (2010) national prices. Data on the country-specific GDP price indices and PPP rates are taken from the MSTI data base.

[b] Available from 2000 onwards.

[c] OECD national account data, https://stats.oecd.org, downloaded 06.07.2022.

[d] cf. Cornell University et al. (2020).

**Table 2**
Summary statistics.

| | N | Mean | S.D. | p10 | p50 | p90 |
|---|---|---|---|---|---|---|
| $ln(GovFinRD)$ | 537 | 8.046 | 1.643 | 5.754 | 7.868 | 10.002 |
| $ln(GBARD)$ | 604 | 8.063 | 1.628 | 5.786 | 7.990 | 9.993 |
| $ln(RDTax)$ | 492 | 4.291 | 3.240 | 0.000 | 5.198 | 8.323 |
| $ln(RDTaxSub)$ | 492 | 8.146 | 1.723 | 5.764 | 8.083 | 10.219 |
| $Gr(GovFinRD)$ | 479 | 2.989 | 8.055 | −5.605 | 2.381 | 12.568 |
| $Gr(GBARD)$ | 589 | 2.840 | 8.187 | −5.559 | 2.232 | 12.796 |
| $Gr(RDTax)$ | 414 | 2.452 | 10.762 | −8.824 | 0.000 | 15.247 |
| $Gr(RDTaxSub)$ | 455 | 3.592 | 8.654 | −5.539 | 3.115 | 14.022 |
| $Gr(GDP)$ | 611 | 2.672 | 2.950 | −0.452 | 2.731 | 5.786 |
| $ln(GDP)$ | 611 | 13.232 | 1.384 | 11.284 | 12.945 | 14.898 |
| $Surplus$ | 611 | −2.455 | 3.521 | −6.643 | −2.289 | 1.336 |
| $Debt$ | 611 | 78.901 | 39.825 | 36.364 | 70.850 | 126.605 |
| $Interest$ | 611 | 3.932 | 2.470 | 0.719 | 4.095 | 6.402 |

*Notes:* $GovFinRD$, $GBARD$, and $GDP$: million PPP $ in constant (2010) national prices. We removed outlier observations with implausible increases and decreases in $GovFinRD$ and $GBARD$ defined as cases where growth was outside of 1.5 times the inter-quartile range, calculated within business cycle stages and country groups.

exogenous regressors while the A-B estimator allows for endogenous regressors. The A-B estimates confirm consistency, as both common specification tests, the A-B test on the lack of second-order autocorrelation in first-differences residuals and the Hansen test on overidentifying restrictions, do not reject the null hypothesis of instrument validity.[23]

Regarding the coefficient of GDP growth, the results confirm that public R&D expenditure is procyclical. The A-B estimates show a positive and significant impact of about 0.293 on $ln(GovFinRD)$ ($p < 0.05$). The estimate of the cyclicality of $ln(GBARD)$ in model (6) is slightly larger, albeit at a lower level of statistical significance (0.328, $p < 0.10$). The LSDVC results yield a coefficient of 0.445 and 0.337 for $ln(GovFinRD)$ and $ln(GBARD)$ in models (5) and (7), respectively. Both estimates are significant at the 1% level, respectively. In summary, and taking the LSDVC specifications as our preferred models, we conclude that, when considering the entire business cycle, a one percentage point increase in GDP growth relates to a 0.45 percent increase in government-financed R&D and a 0.34 percent increase in GBARD. This result also suggests that governments are planning a less procyclical response to business cycles than they actually realize.

Models (8), (9), and (10), shown in Table 3, use the growth rate of public R&D, $Gr(GovFinRD)$ and $Gr(GBARD)$, as outcome variables. Compared to the previous specifications, these models implicitly factor out country-specific unobserved heterogeneities in the expenditure levels by calculating relative year-over-year differences. OLS is used for the static growth model (model (8)) and the dynamic growth model (model (9)) for $Gr(GovFinRD)$, while model (10) compares the dynamic results using $Gr(GBARD)$ as the outcome variable.[24] The same pattern emerges from the estimates across all three of these models:

[23] For the A-B estimates, we instrument the endogenous variable $y_{it-1} - y_{it-2}$ only with the two-year lagged level of $y$, i.e. $y_{it-2}$, and assume that all other regressors are strictly exogenous. We made this choice to comply with the recommendation to keep the number of instruments below $N$ and to reduce the problem of instrument proliferation given the small number of countries $N$ (Roodman, 2009). Table 10 in the Appendix shows that the estimated coefficients are similar in magnitude but less precisely estimated when we increase the number of instruments by allowing more lagged levels of $y$ and $Gr(GDP)$ to be predetermined or endogenous as well. Overall, our results are very robust to the choice of the set of instruments.

[24] While models (2) to (7) confirm country fixed effects in the log-levels of public R&D, we do not find evidence for country fixed effects in the growth rate models of public R&D and thus leave them out in models (8) to (10). As the growth specifications do not include country fixed effects, it

**Table 3**
Effect of business cycles on public R&D expenditures.

| $y_{it}$ | Level | | | | | | | Growth | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $ln(GovFinRD)_{it}$ | | | | | $ln(GBARD)_{it}$ | | $Gr(GovFinRD)_{it}$ | | $Gr(GBARD)_{it}$ |
| | (1) OLS | (2) FE | (3) FD | (4) A-B | (5) LSDVC | (6) A-B | (7) LSDVC | (8) OLS | (9) OLS | (10) OLS |
| $Gr(GDP)_{it}$ | −0.174 | 0.243 | 0.451** | 0.293** | 0.445*** | 0.328* | 0.337*** | 0.467*** | 0.425*** | 0.405*** |
| | (0.631) | (0.289) | (0.173) | (0.146) | (0.123) | (0.181) | (0.126) | (0.159) | (0.148) | (0.145) |
| $ln(GDP)_{it-1}$ | 1.137*** | 1.311*** | 0.651** | 0.223 | 0.122** | 0.187 | 0.026 | 0.000 | −0.000 | −0.003 |
| | (0.042) | (0.125) | (0.250) | (0.165) | (0.051) | (0.162) | (0.053) | (0.002) | (0.002) | (0.002) |
| $Surplus_{it-1}$ | 1.651 | −0.482 | −0.109 | 0.303 | 0.390*** | 0.554** | 0.654*** | 0.455*** | 0.408*** | 0.602*** |
| | (1.078) | (0.558) | (0.240) | (0.246) | (0.135) | (0.257) | (0.144) | (0.155) | (0.131) | (0.098) |
| $Debt_{it-1}$ | −0.116 | −0.002 | −0.122 | −0.077 | −0.046** | −0.061* | −0.008 | −0.007 | −0.004 | 0.023 |
| | (0.088) | (0.121) | (0.105) | (0.065) | (0.023) | (0.036) | (0.027) | (0.015) | (0.014) | (0.014) |
| $Interest_{it-1}$ | −1.063 | 1.013 | −0.282 | 0.233 | 0.098 | 0.119 | 0.068 | 0.163 | 0.197 | 0.284 |
| | (0.876) | (0.783) | (0.361) | (0.577) | (0.293) | (0.439) | (0.340) | (0.291) | (0.254) | (0.251) |
| $y_{it-1}$ | | | | 0.905*** | 0.927*** | 0.840*** | 0.945*** | | 0.121 | 0.152*** |
| | | | | (0.126) | (0.028) | (0.128) | (0.023) | | (0.094) | (0.050) |
| Constant | −6.827*** | −9.375*** | 0.013 | | | | | 0.029 | 0.024 | 0.039 |
| | (0.619) | (1.662) | (0.008) | | | | | (0.033) | (0.032) | (0.030) |
| FE | NO | YES | YES | YES | YES | YES | YES | NO | NO | NO |
| N * T | 503 | 503 | 429 | 424 | 454 | 521 | 558 | 455 | 448 | 550 |
| $R^2$ | 0.959 | 0.687 | 0.070 | | | | | 0.082 | 0.089 | 0.125 |
| Hansen Test | | | | 20.696 | | 22.847 | | | | |
| ($p$-value) | | | | (0.540) | | (0.410) | | | | |
| Sargan Test | | | | 27.015 | | 33.059 | | | | |
| ($p$-value) | | | | (0.211) | | (0.061) | | | | |
| A-B Test | | | | | | | | | | |
| AR(1) | | | | −2.286 | | −3.165 | | | | |
| ($p$-value) | | | | (0.022) | | (0.002) | | | | |
| AR(2) | | | | 0.771 | | −1.147 | | | | |
| ($p$-value) | | | | (0.441) | | (0.251) | | | | |

*Notes:* This table provides regression models on the effect of business cycles on the level and growth rate of $GovFinRD$ and $GBARD$. Standard errors are clustered by country, except for bootstrapped standard errors for LSDVC. Coefficients of $Gr(GDP)$, $Surplus$, $Debt$, and $Interest$ are scaled up with a factor of 100. Each model was specified on the full range of available information, so some country-year observations are included in the level specifications where growth was not available, and some observations have $GovFinRD$ observed but $GBARD$ missing. See Table 9 in the Appendix for the estimates on the smaller joint sample, where the results do not differ substantially. The A-B estimates instrument the endogenous variable $y_{it-1} - y_{it-2}$ with the two-year lagged level of $y$, i.e. $y_{it-2}$. All other regressors are assumed to be strictly exogenous. See Table 10 in the Appendix for alternative specifications that allow for more lagged levels of $y$ as instruments and that treat $Gr(GDP)$ to be predetermined or endogenous.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

The coefficient of GDP growth is significantly positive, confirming the *procyclicality* of public R&D over the entire business cycle. Regarding the interpretation of the coefficient of our focus variable, it changes from a semi-elasticity between GDP growth and the level of public R&D spending to a unit change relationship between GDP growth and the growth of public R&D in models (8), (9), and (10). That is, a one percentage point increase in the growth rate of GDP co-occurs with a 0.43 percentage point increase in the growth rate of $GovFinRD$ ($p < 0.01$) and a 0.41 percentage point increase in the growth rate of $GBARD$ ($p < 0.01$).

Our result of procyclicality suggests that, on average, the pressure for fiscal consolidation is stronger during recessions than is any concern about the long-term impact of declining public R&D investment. Yet, it can still be the case that governments adopt a different policy stance during recessions than in other phases of the business cycle, and that countries with stronger innovation track records set public R&D policies differently from countries with weaker track records. In Section 4.2, we further investigate to what extent average procyclicality is carried across the entire business cycle, and to what extent it is shared among countries with different levels of innovation performance.

Regarding the other explanatory variables, we can confirm that public R&D expenditure is persistent to a significant degree, as the dynamic term $y_{it-1}$ is significantly positive across most dynamic specifications.[25] Thus, persistence holds for both the level of public R&D expenditure and the growth rate of GBARD. However, not surprisingly, we find that persistence is much higher in the level of expenditure than it is in the growth of expenditure. Furthermore, and as expected, we find the size of the economy to show a positive relation to the level of public R&D expenditures, but this effect vanishes in the growth models. The growth of public R&D expenditures is significantly positively related to government budget surplus. Public debt has the expected negative coefficient in most regressions, but it is significant only in the preferred dynamic LSDVC estimates for $Gr(GovFinRD)$ and in the A-B estimates for $ln(GBARD)$. No significant pattern emerges for long-term interest rates.

Table 4 presents estimates of the cyclicality of the log-level and growth rate of public R&D spending by sector of performance (business, government and higher education). Across the business cycle, governments might shift public R&D expenditures between sectors. For instance, they might expand budgets for R&D support schemes for the business sector in response to economic crises to compensate for falling privately financed R&D in the business sector. Therefore, we split $GovFinRD$ by public R&D performed in the business, government, and higher education sectors, and estimate each sector's cyclicality separately. The results in model (3) to (6) confirm procyclicality of public R&D spending assigned to the government and higher education sectors. Interestingly, model (1) and (2) show a different pattern for public R&D assigned to the business sector. It behaves acyclical, which means that it remains stable across the business cycle. This is in line with the idea that governments, on the whole, do not cut public R&D budgets for the business sector in recessions but rather attempt to safeguard private R&D through stable R&D policy spending.

is not necessary to instrument the dynamic term, although doing so does not critically affect the estimated coefficients.

[25] While the dynamic term turns insignificant in column (9), which estimates $Gr(GovFinRD)$ with a dynamic term, it persists in column (10), estimating $Gr(GBARD)$.

**Table 4**
Effect of business cycles on public R&D spending by sector of performance.

| $y_{it}$ | Business | | Government | | Higher Education | |
|---|---|---|---|---|---|---|
| | Level | Growth | Level | Growth | Level | Growth |
| | (1) LSDVC | (2) OLS | (3) LSDVC | (4) OLS | (5) LSDVC | (6) OLS |
| $Gr(GDP)_{it}$ | 0.245 | −0.231 | 0.613** | 0.548*** | 0.500*** | 0.511*** |
| | (0.514) | (0.242) | (0.261) | (0.186) | (0.183) | (0.172) |
| $ln(GDP)_{it-1}$ | 0.422*** | 0.003 | 0.021 | −0.003 | 0.180*** | 0.001 |
| | (0.148) | (0.006) | (0.083) | (0.004) | (0.064) | (0.003) |
| $Surplus_{it-1}$ | −0.285 | 0.248 | −0.024 | 0.219 | 0.126 | 0.360*** |
| | (0.430) | (0.364) | (0.258) | (0.140) | (0.218) | (0.072) |
| $Debt_{it-1}$ | −0.085 | −0.013 | −0.045 | −0.002 | −0.045 | −0.018 |
| | (0.085) | (0.017) | (0.052) | (0.018) | (0.036) | (0.010) |
| $Interest_{it-1}$ | 1.515 | 0.188 | 0.193 | 0.398 | 0.649* | 0.468*** |
| | (1.084) | (0.314) | (0.517) | (0.404) | (0.385) | (0.161) |
| $y_{it-1}$ | 0.816*** | 0.073 | 0.961*** | −0.005 | 0.922*** | 0.056 |
| | (0.035) | (0.061) | (0.029) | (0.043) | (0.024) | (0.101) |
| Constant | | −0.001 | | 0.041 | | 0.020 |
| | | (0.081) | | (0.053) | | (0.040) |
| FE | YES | NO | YES | NO | YES | NO |
| N * T | 452 | 343 | 458 | 415 | 460 | 406 |
| $R^2$ | | 0.014 | | 0.047 | | 0.095 |

*Notes:* This table provides regressions on the effect of business cycles on the government-financed R&D allocated to the business, government, and higher education sectors. The coefficients of $Gr(GDP)$, $Surplus$, $Debt$, and $Interest$ are scaled up with a factor of 100. Standard errors in OLS regressions are clustered by country. Bootstrapped standard errors for LSDVC. For additional notes, see Table 3.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

Considering the general procyclicality of public R&D spending, this result provides an important nuance: The procyclicality in total public R&D expenditure stems primarily from procyclicalities in public R&D assigned to the government and higher education sector.

Table 5 presents estimates of the cyclicality of R&D tax incentives, $RDTax$, in columns (1) and (2). While column (1) shows estimation results for the (log-)level of R&D tax incentives using a dynamic specification and the LSDVC estimator similar to model (5) in Table 3, column (2) uses the growth of R&D tax incentives as outcome variable. Columns (3) and (4) additionally investigate the cyclicality of the combined government budget for public R&D spending and R&D tax incentives $RDTaxSub$. Concerning the level of R&D tax incentives, the LSDVC estimate yields a large and positive coefficient (0.892), which is however not statistically significant ($p > 0.10$). That is, we see no systematic procyclical or countercyclical variation in the level of R&D tax incentives with GDP growth. At the same time, the growth rate of R&D tax incentives is found to be procyclical in column 2 (0.398, $p < 0.05$). While the evidence on the cyclicality of R&D tax incentives is more mixed than the evidence for the cyclicality of public R&D spending, the data are still indicative of a procyclical pattern. One reason for this somewhat mixed picture, compared to results on the cyclicality of public R&D spending, could be the fact that almost all countries have a cap on R&D tax incentives which is sufficiently low so that most changes in private R&D expenditures do not result in changes in claimed R&D tax incentives.

The evolution of the combined direct and indirect measures of R&D support, in columns (3) and (4), remains procyclical at comparable coefficient sizes as those presented in Table 3 (level: 0.379, $p < 0.05$, growth rate: 0.469, $p < 0.01$). Thus, the previously observed procyclicality in public R&D spending is not significantly strengthened or weakened by the inclusion of R&D tax incentives.

### *4.2. Asymmetry and heterogeneity in the cyclicality of public R&D*

The results in Section 4.1 show that, on average, public R&D expenditures and government budgets for R&D behave procyclically. But governments might still behave asymmetrically between recession periods and non-recession periods, and public R&D policy responses might be substantial heterogeneous depending on a country's innovation status.

To study these asymmetries and heterogeneities in public R&D responses in more detail, we extend the benchmark model on growth rates by allowing for differences in cyclicalities between recession and non-recession periods, between countries based on their innovation status, and the combination thereof. In each specification, we interact dummies for innovation status, and/or the recession indicator with the growth rate of GDP. Note that we do not use a reference category in the interactions, so the estimated coefficients of $Gr(GDP)$ represent the cyclicality of each subgroup, not the differences between that reference category and a subgroup.

Table 6 shows the results for the growth in public R&D expenditures. Starting with the question concerning whether countries generally exhibit asymmetric cyclical behavior with regard to their public R&D expenditures, models (1) and (4) show that the coefficient of $Gr(GDP)$ varies between recession periods and non-recession periods. These results, which are comparable across both outcome variables, $Gr(GovFinRD)$ and $Gr(GBARD)$, highlight that, after controlling for observed and unobserved country effects, the average procyclicality is driven by non-recession periods. During recessions, however, the relationship between GDP growth and growth in public R&D becomes insignificant, implying stable public R&D budgets despite negative GDP growth. Overall, our results confirm that public R&D reacts differently to expansion than it does to contraction phases. In this regard, the results extend Ouyang's (2011) finding of asymmetric responses of private R&D expenditure to demand shocks. However, strikingly, the directions of public and private R&D responses differ over the business cycle and seem to counteract each other. While Ouyang (2011) reports a counter-cyclical effect in booms and a procyclical effect in recessions for private R&D, our results suggest procyclical behavior in non-recession periods and acyclical behavior in recession periods for public R&D.

Differences in public R&D policy responses based on countries' innovation status are addressed in models (2) and (5) of Table 6. Most of the average procyclicality documented in Table 3 seems to be driven by moderate innovators and innovation followers. The coefficient of GDP growth is positive and significant for both groups. In contrast, innovation leaders clearly set *acyclical* public R&D policies over the whole business cycle, as indicated by the non-significant coefficients of $Gr(GDP)$. Overall, our results show clearly that policy responses

**Table 5**
Effect of business cycles on R&D spending, including R&D tax incentives.

| $y_{it}$ | $ln(RDTax)_{it}$ (1) LSDVC | $Gr(RDTax)_{it}$ (2) OLS | $ln(RDTaxSub)_{it}$ (3) LSDVC | $Gr(RDTaxSub)_{it}$ (4) OLS |
|---|---|---|---|---|
| $Gr(GDP)_{it}$ | 0.892 | 0.398** | 0.379** | 0.469*** |
| | (1.159) | (0.186) | (0.169) | (0.156) |
| $ln(GDP)_{it-1}$ | 0.278 | 0.001 | 0.109 | −0.003 |
| | (0.470) | (0.005) | (0.075) | (0.003) |
| $Surplus_{it-1}$ | −0.312 | −0.305* | 0.553*** | 0.533*** |
| | (1.187) | (0.149) | (0.178) | (0.138) |
| $Debt_{it-1}$ | −0.080 | 0.023 | 0.003 | 0.025* |
| | (0.268) | (0.027) | (0.040) | (0.013) |
| $Interest_{it-1}$ | −1.625 | −0.012 | 0.097 | 0.291 |
| | (2.509) | (0.368) | (0.362) | (0.338) |
| $y_{it-1}$ | 0.916*** | 0.119 | 0.900*** | 0.143** |
| | (0.033) | (0.071) | (0.033) | (0.056) |
| Constant | | −0.033 | | 0.043 |
| | | (0.056) | | (0.036) |
| FE | YES | NO | YES | NO |
| N * T | 452 | 336 | 452 | 419 |
| $R^2$ | | 0.063 | | 0.102 |

*Notes:* This table provides regressions on the effect of the business cycle on the tax incentive support for R&D, and the combination of government budgets for R&D and tax incentive support for R&D. Data on R&D tax incentives stems from the OECD R&D Tax incentives database (OECD, 2022b) and is available from 2000 onward. The coefficients of $Gr(GDP)$, $Surplus$, $Debt$, and $Interest$ are scaled up with a factor of 100. Standard errors in OLS regressions are clustered by country. Bootstrapped standard errors for LSDVC. For additional notes, see Table 3.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

regarding the cyclicality of public R&D are contingent on a country's innovation status.

Table 6 also shows the combined effect of heterogeneity based on the countries' innovation status and of asymmetry by recession period in models (3) and (6). We find asymmetric behavior between recession and non-recession periods for all three country groups but with intriguing differences across country groups. Again, leading innovators differ from innovation followers and moderate innovators. Most importantly, innovation leaders pursue *countercyclical* public R&D strategies during recession periods. For government-financed R&D, the coefficient of $Gr(GDP)$ is significantly negative during recessions (−0.480, $p < 0.05$), and the same holds for the growth of $GBARD$ (−0.600, $p < 0.10$). In contrast, outside of recession periods there is evidence of *acylicality* for government-financed R&D (0.246, $p > 0.10$) and even weak evidence of procyclicality for $GBARD$ (0.410, $p < 0.10$) in innovation leading countries. This response pattern of innovation leaders is not observed for innovation followers and moderate innovators, where both measures of public R&D spending evolve strongly *procyclical* outside of recessions but are*acyclically* stable during recessions.

In summary, the analysis in Table 6 highlights some important asymmetries and heterogeneities that extend and nuance the finding of general procyclicality. First, in recessions, governments deviate from their generally procyclical public R&D spending behavior and on average leave public R&D at the same level despite negative GDP growth. The reason for this asymmetric behavior is rooted in a greater need for (Keynesian) stabilizing interventions, including in public R&D, among policymakers during recessions and the presence of automatic stabilizers like the continued payment of researchers' wages in public universities and research institutes. These stabilizers cause public R&D spending to decrease less than it would if policy had been conducted as usual. Second, moderate innovators and innovation followers show more procyclical public R&D spending patterns than innovation leaders. Third, although we observe acyclicality in recessions on average across all countries, innovation leaders even pursue countercyclical public R&D policies during recessions. By increasing public spending on R&D in periods when private investment in R&D is lagging, total R&D investment in these countries remains closer to that in non-crisis times, effectively increasing their lead over other countries. The latter finding is further illustrated in Fig. 2, which plots the predicted relations between GDP growth and the growth rate of $GovFinRD$ based on column (3) of Table 6 by country group. Only in the case of innovation leaders does the relation turn countercyclical during recessions. For innovation followers and moderate innovators, on the other hand, procyclical behavior outside recessions turns into acyclical behavior in the crisis.

## 5. Conclusion

We study the cyclicality of public R&D spending, with a special emphasis on how governments respond to economic crises. Specifically, we ask whether governments compensate for predominantly procyclical private investment in R&D by increasing public R&D spending during economic contractions or succumb to the pressure for fiscal consolidation. Our empirical analysis examines GBARD and government-financed R&D – reflecting ex-ante and ex-post public R&D spending, respectively – of 29 OECD countries between 1995 and 2019. Our study contributes to the scarce and mainly descriptive literature on business cycles and public R&D by studying the cyclicality of public R&D in an econometric framework that allows us to control for observed and unobserved country-specific heterogeneity. Our paper also aims to deepen understanding of the cyclicality of public R&D by investigating asymmetries in its cyclicality across recessions and non-recession periods, and by investigating international heterogeneities in cyclicalities.

Our results reveal a nuanced pattern. On average, and considered over the whole business cycle, public R&D expenditures are estimated to be procyclical. This suggests that, on the whole, governments do not compensate for declining (increasing) private R&D spending by increasing (declining) public R&D spending. This procyclicality is mainly driven by spending aimed towards the government and higher education sectors, whereas public R&D performed in the business sector is estimated to be acyclical. Whereas the level of public R&D expenditures does not increase during crises, public R&D is thus implicitly refocused on the private sector through spending cuts in other sectors.

However, this general result hides important asymmetric behavior in recession and non-recession periods. Averaged across all countries, public R&D is procyclical outside of recessions but becomes acyclical during recessions. Thus, governments deviate from their generally

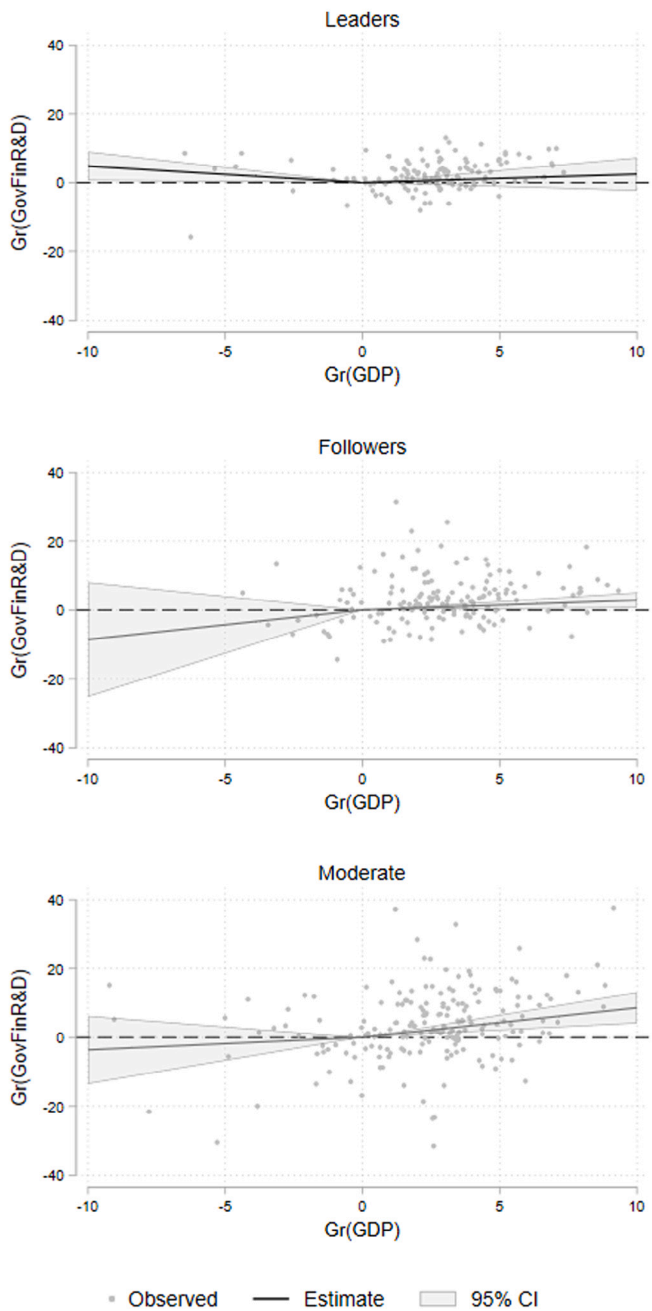


**Fig. 2.** Growth of public R&D by GDP growth by country group. *Notes:* Each graph plots the predicted relation between GDP growth and the growth of $GovFinRD$, based on column (3) of Table 6. GDP shocks larger than 10 percentage points are not included. The line shows a linear fit. The areas show 95% confidence intervals. $n = 476$.

procyclical public R&D spending behavior during recessions and leave public R&D budgets largely unchanged, despite negative GDP growth and increased pressure to cut back public spending amid falling tax income, thereby providing some counterweight for procyclical private R&D spending (Aghion et al., 2010, 2012).

Yet, not all governments behave the same: our results point to strong national heterogeneity in public R&D responses along the country's innovation performance. Public R&D spending of the strongest innovators according to the Global Innovation Index is generally acyclical, and even countercyclical during recessions, actively compensating for falling private R&D spending. Countries with weaker innovation track records behave procyclically, driving our overall finding of procyclicality. While these countries turn to acyclical spending during recessions, they do not compensate for falling private R&D spending in the same way as leading countries do. This pattern contributes to a widening innovation gap, where weaker innovators fall more behind to leading innovators during recessions.

On the whole, our findings contribute to the literature aiming to understand policy responses to the Great Recession (e.g. Izsak et al., 2013; Makkonen, 2013; OECD, 2012) by providing estimates of the cyclicality of public R&D spending, and by broadening the frame of reference to a wider time period. Our findings confirm the notion that public R&D enjoys a higher policy priority during recessions than outside of them, as documented by Izsak et al. (2013) and OECD (2012) in the case of the Great Recession. At the same time, our findings indicate that there remain large international heterogeneities in policy responses, as has been previously documented in case studies (Brautzsch et al., 2015; Cruz-Castro and Sanz-Menéndez, 2016; Kastrinos, 2013) and the literature addressing the intra-European convergence of R&D (Archibugi et al., 2020). Compared to these studies, we offer complementary econometric evidence confirming that the international heterogeneities are strong.

Our findings have important implications for R&D policy. Given the strong evidence that private R&D investment behaves procyclically, except for financially unconstrained firms (e.g. Aghion et al., 2012), the degree to which public policy can compensate for falling private R&D spending during recessions seems key to safeguarding long-term growth prospects in economic crises. The evidence shown here indicates then, on the whole, a failure of public R&D policy: only few countries engage in Keynesian public R&D policies by actively compensating for falling private R&D spending during recessions through public R&D spending. At the same time, our results still show some indication that governments are aware of the importance of public R&D, as public R&D spending becomes generally acyclical during recessions, and public R&D aimed at the business sector is acyclical in general. However, maintaining public R&D spending is still a step short of compensating for falling private R&D spending.

Our finding that only few countries actively compensate falling R&D expenditures in the private sector with increases in public R&D during economic crises, while most countries do not, means that most governments should do more to close this gap. In the long run, failure to address these discrepancies could contribute to long-term international differences in technology-driven growth, as is further underscored when comparing case studies of countries with countercyclical public R&D spending responses during the Great Recession, e.g., Germany (Brautzsch et al., 2015) and countries where public R&D programs were slashed, e.g. Spain and Greece (Cruz-Castro and Sanz-Menéndez, 2016; Kastrinos, 2013). Given the cumulative and path-dependent nature of investment in R&D and the associated human capital needs, such short-term cuts to public R&D programs will most likely have negative long-term implications. The differences in policies might be at the root of a widening innovation gap: innovation leaders might experience smaller (or no) setbacks in terms of innovation because of business cycles, while others do. In that regard, our findings align with the ones of Censolo and Colombo (2019), who document substantial heterogeneity in total R&D spending in Europe. Comparing core and peripheral European countries, they find that core countries tend to invest countercyclically, whereas peripheral countries invest procyclically. We build on this by expanding the insights of Censolo and Colombo (2019) to a broader framework of innovation performance and by focusing specifically on the cyclicality of public R&D spending.

To the extent that policymakers consider reducing differences between countries in innovative capacity a priority, they should still increase their resilience to crises by taking on a more countercyclical stance toward public R&D. For example, European policymakers might find investing in countercyclical R&D programs for countries that currently lag behind the innovation frontier or allowing them to exempt public R&D expenditure from fiscal consolidation to stimulate public R&D expenditures during economic crises especially beneficial. Of course, a full assessment of the welfare-related implications of a growing innovation gap between innovation-leading and innovation-lagging countries would also need to consider the effects of R&D on economic growth. In particular, future research could investigate whether countries that implement countercyclical public R&D strategies also have greater resilience to economic crises.

Another area for future research concerns the most recent economic crisis, namely the recession induced by the COVID-19 pandemic. In this study, we explicitly omit this recession as it is by nature different from a purely economic crisis. In particular, the public R&D policy responses related to the creation of the COVID vaccines entailed large public R&D investments. Indeed, inspection of the evolution in public R&D expenditures between 2019 and 2020 indicates a significant increase in combined public R&D spending across all countries for which data was available.[26] An important area for future research would be to disentangle what part of this growth in public R&D is due to the specific needs of battling the COVID-19 pandemic, and which part is because of policy learning from past economic crises and the implementation of countercyclical public R&D policies.

## CRediT authorship contribution statement

**Maikel Pellens:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Bettina Peters:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Martin Hud:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Christian Rammer:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Georg Licht:** Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Maikel Pellens reports financial support was provided by European Commission Seventh Framework Programme for Research and Technological Development. Bettina Peters reports financial support was provided by European Commission Seventh Framework Programme for Research and Technological Development. Christian Rammer reports financial support was provided by European Commission Seventh Framework Programme for Research and Technological Development. Georg Licht reports financial support was provided by European Commission Seventh Framework Programme for Research and Technological Development.

[26] We consulted the MSTI data on this question in February 2024.

## Data availability

Data will be made available on request.

## Appendix

See Tables 7–10.

**Table 6**
Effect of business cycles on public R&D expenditures, by country innovation status and business cycle phase.

| $y_{it}$ | $Gr(GovFinRD)_{it}$ | | | $Gr(GBARD)_{it}$ | | |
|---|---|---|---|---|---|---|
| | (1) OLS | (2) OLS | (3) OLS | (4) OLS | (5) OLS | (6) OLS |
| $Gr(GDP)_{it}$ × No rec | 0.488** | | | 0.615** | | |
| | (0.219) | | | (0.234) | | |
| $Gr(GDP)_{it}$ × Rec | 0.283 | | | −0.193 | | |
| | (0.408) | | | (0.491) | | |
| $Gr(GDP)_{it}$ × L | | 0.082 | | | 0.158 | |
| | | (0.176) | | | (0.147) | |
| $Gr(GDP)_{it}$ × F | | 0.253** | | | 0.403** | |
| | | (0.097) | | | (0.185) | |
| $Gr(GDP)_{it}$ × M | | 0.717*** | | | 0.598** | |
| | | (0.172) | | | (0.249) | |
| $Gr(GDP)_{it}$ × L × No rec | | | 0.246 | | | 0.410* |
| | | | (0.247) | | | (0.209) |
| $Gr(GDP)_{it}$ × L × Rec | | | −0.480** | | | −0.600* |
| | | | (0.216) | | | (0.349) |
| $Gr(GDP)_{it}$ × F × No rec | | | 0.287** | | | 0.527** |
| | | | (0.115) | | | (0.242) |
| $Gr(GDP)_{it}$ × F × Rec | | | 0.857 | | | 0.231 |
| | | | (0.850) | | | (0.396) |
| $Gr(GDP)_{it}$ × M × No rec | | | 0.860*** | | | 0.878*** |
| | | | (0.231) | | | (0.300) |
| $Gr(GDP)_{it}$ × M × Rec | | | 0.363 | | | −0.100 |
| | | | (0.505) | | | (0.656) |
| $ln(GDP)_{it-1}$ | 0.002 | 0.002 | 0.001 | −0.001 | 0.000 | −0.000 |
| | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| $Surplus_{it-1}$ | 0.412*** | 0.435*** | 0.442*** | 0.615*** | 0.632*** | 0.648*** |
| | (0.133) | (0.124) | (0.135) | (0.104) | (0.099) | (0.111) |
| $Debt_{it-1}$ | −0.005 | −0.004 | 0.000 | 0.022 | 0.019 | 0.023 |
| | (0.014) | (0.014) | (0.015) | (0.014) | (0.015) | (0.015) |
| $Interest_{it-1}$ | 0.223 | 0.194 | 0.176 | 0.299 | 0.316 | 0.272 |
| | (0.252) | (0.247) | (0.226) | (0.246) | (0.245) | (0.236) |
| $y_{t-1}$ | 0.124 | 0.108 | 0.113 | 0.157*** | 0.147** | 0.147** |
| | (0.093) | (0.092) | (0.091) | (0.052) | (0.054) | (0.055) |
| N * T | 448 | 448 | 448 | 550 | 550 | 550 |
| $R^2$ | 0.211 | 0.226 | 0.230 | 0.236 | 0.235 | 0.244 |

*Notes:* This table provides OLS regressions for $Gr(GovFinRD)$ and $Gr(GBARD)$. We allow the effect of the business cycle, $Gr(GDP)$, to vary by recession period, country innovation status, and the combination thereof. Each interacted coefficient represents the coefficient of $Gr(GDP)$ for that subgroup. L: leading innovators. F: innovation followers. M: moderate innovators. Rec and No rec indicate recession and non-recession periods, respectively. Standard errors are clustered by country. For additional notes, see Table 3.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

**Table 7**
Correlation matrix.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. $ln(GovFinRD)$ | 1.000 | | | | | | | | | | | | |
| 2. $ln(GBARD)$ | 0.994*** | 1.000 | | | | | | | | | | | |
| 3. $ln(RDTax)$ | 0.607*** | 0.588*** | 1.000 | | | | | | | | | | |
| 4. $ln(RDTaxSub)$ | 0.995*** | 0.998*** | 0.629*** | 1.000 | | | | | | | | | |
| 5. $Gr(GovFinRD)$ | −0.046 | −0.064 | −0.060 | −0.033 | 1.000 | | | | | | | | |
| 6. $Gr(GBARD)$ | −0.048 | −0.066 | −0.133** | −0.066 | 0.467*** | 1.000 | | | | | | | |
| 7. $Gr(RDTax)$ | 0.075 | 0.074 | 0.171*** | 0.086 | 0.054 | −0.004 | 1.000 | | | | | | |
| 8. $Gr(RDTaxSub)$ | −0.030 | −0.061 | −0.076 | −0.065 | 0.400*** | 0.932*** | 0.164** | 1.000 | | | | | |
| 9. $Gr(GDP)$ | −0.053 | −0.065 | −0.089* | −0.076 | 0.214*** | 0.187*** | 0.144** | 0.171*** | 1.000 | | | | |
| 10. $ln(GDP)$ | 0.977*** | 0.975*** | 0.621*** | 0.979*** | −0.065 | −0.080 | 0.072 | −0.071 | −0.057 | 1.000 | | | |
| 11. $Surplus$ | −0.082 | −0.096* | −0.232*** | −0.118** | 0.164*** | 0.198*** | −0.040 | 0.137** | 0.274*** | −0.147*** | 1.000 | | |
| 12. $Debt$ | 0.416*** | 0.419*** | 0.495*** | 0.486*** | −0.125** | −0.061 | 0.089 | −0.019 | −0.112** | 0.458*** | −0.353*** | 1.000 | |
| 13. $Interest$ | −0.170*** | −0.151*** | −0.142** | −0.210*** | −0.105* | −0.075 | −0.081 | −0.048 | −0.187*** | −0.128** | −0.320*** | −0.068 | 1.000 |

*Notes:* $GovFinRD$, $GBARD$, and $GDP$: million 2010 PPP.
* Significance level: $p < 0.1$.
** Significance level: $p < 0.05$.
*** Significance level: $p < 0.01$.

**Table 8**
Included countries.

| Country | Freq | GII | | Years | |
|---|---|---|---|---|---|
| | | Rank | Group | First | Last |
| Australia | 25 | 23 | F | 1995 | 2019 |
| Austria | 25 | 19 | F | 1995 | 2019 |
| Belgium | 25 | 22 | F | 1995 | 2019 |
| Canada | 24 | 17 | F | 1995 | 2018 |
| Czech Republic | 19 | 24 | M | 2001 | 2019 |
| Denmark | 25 | 6 | L | 1995 | 2019 |
| Finland | 25 | 7 | L | 1995 | 2019 |
| France | 25 | 12 | F | 1995 | 2019 |
| Germany | 25 | 9 | L | 1995 | 2019 |
| Greece | 22 | 43 | M | 1998 | 2019 |
| Hungary | 15 | 35 | M | 2005 | 2019 |
| Ireland | 22 | 15 | F | 1998 | 2019 |
| Israel | 19 | 13 | F | 2001 | 2019 |
| Italy | 22 | 28 | M | 1995 | 2019 |
| Japan | 15 | 16 | F | 2005 | 2019 |
| Korea | 12 | 10 | L | 2008 | 2019 |
| Latvia | 19 | 36 | M | 2001 | 2019 |
| Lithuania | 16 | 40 | M | 2004 | 2019 |
| Luxembourg | 17 | 18 | F | 2000 | 2019 |
| Netherlands | 25 | 5 | L | 1995 | 2019 |
| Poland | 17 | 38 | M | 2001 | 2019 |
| Portugal | 25 | 31 | M | 1995 | 2019 |
| Slovakia | 19 | 39 | M | 2001 | 2019 |
| Slovenia | 17 | 32 | M | 2003 | 2019 |
| Spain | 25 | 30 | M | 1995 | 2019 |
| Sweden | 24 | 2 | L | 1995 | 2019 |
| Switzerland | 12 | 1 | L | 2000 | 2019 |
| United Kingdom | 25 | 4 | L | 1995 | 2019 |
| United States | 25 | 3 | L | 1995 | 2019 |

*Notes:* This table shows for each country in the final dataset: (1) the number of observations (Freq), (2) the country's innovation rank according to 2020 Global Innovation Index (GII Rank). GII Status indicates the grouping used in the analysis. L = Leader; F = Follower; M: Moderate, (3) the first and last observed year.

**Table 9**
Effect of business cycles on public R&D: joint sample.

| $y_{it}$ | Level | | | | | | | Growth | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $ln(GovFinRD)_{it}$ | | | | | $ln(GBARD)_{it}$ | | $Gr(GovFinRD)_{it}$ | | $Gr(GBARD)_{it}$ |
| | (1) OLS | (2) FE | (3) FD | (4) A-B | (5) LSDVC | (6) A-B | (7) LSDVC | (8) OLS | (9) OLS | (10) OLS |
| $Gr(GDP)_{it}$ | −0.038 | 0.206 | 0.447** | 0.319** | 0.456*** | 0.219 | 0.340** | 0.466*** | 0.422*** | 0.355** |
| | (0.641) | (0.322) | (0.178) | (0.141) | (0.126) | (0.192) | (0.150) | (0.162) | (0.151) | (0.152) |
| $ln(GDP)_{it-1}$ | 1.132*** | 1.218*** | 0.611** | 0.335 | 0.102* | 0.287* | 0.039 | −0.001 | −0.001 | −0.000 |
| | (0.044) | (0.118) | (0.261) | (0.227) | (0.052) | (0.166) | (0.053) | (0.002) | (0.002) | (0.002) |
| $Surplus_{it-1}$ | 1.135 | −0.564 | −0.121 | 0.224 | 0.392*** | 0.484* | 0.655*** | 0.459*** | 0.413*** | 0.626*** |
| | (1.077) | (0.552) | (0.244) | (0.292) | (0.123) | (0.293) | (0.135) | (0.156) | (0.134) | (0.130) |
| $Debt_{it-1}$ | −0.091 | −0.035 | −0.139 | −0.063 | −0.044* | −0.046 | −0.024 | −0.005 | −0.002 | 0.021 |
| | (0.097) | (0.107) | (0.108) | (0.070) | (0.023) | (0.047) | (0.025) | (0.015) | (0.013) | (0.016) |
| $Interest_{it-1}$ | −0.985 | 0.378 | −0.383 | 0.130 | −0.040 | 0.174 | −0.062 | 0.153 | 0.186 | 0.274 |
| | (0.959) | (0.648) | (0.348) | (0.494) | (0.266) | (0.700) | (0.330) | (0.290) | (0.254) | (0.316) |
| $y_{it-1}$ | | | | 0.815*** | 0.930*** | 0.722*** | 0.954*** | | 0.116 | 0.142*** |
| | | | | (0.171) | (0.028) | (0.124) | (0.030) | | (0.092) | (0.046) |
| Constant | −6.819*** | −8.117*** | 0.015* | | | | | 0.042 | 0.037 | 0.010 |
| | (0.664) | (1.563) | (0.009) | | | | | (0.034) | (0.034) | (0.025) |
| FE | NO | YES | YES | YES | YES | YES | YES | NO | NO | NO |
| N * T | 449 | 449 | 423 | 418 | 448 | 415 | 444 | 449 | 442 | 440 |
| $R^2$ | 0.962 | 0.698 | 0.079 | | | | | 0.088 | 0.094 | 0.122 |
| Hansen Test | | | | 20.772 | | 21.543 | | | | |
| (*p*-value) | | | | (0.535) | | (0.487) | | | | |
| Sargan Test | | | | 28.915 | | 25.162 | | | | |
| (*p*-value) | | | | (0.147) | | (0.289) | | | | |
| A-B Test | | | | | | | | | | |
| AR(1) | | | | −2.010 | | −2.837 | | | | |
| (*p*-value) | | | | (0.044) | | (0.005) | | | | |
| AR(2) | | | | 0.418 | | −1.068 | | | | |
| (*p*-value) | | | | (0.676) | | (0.285) | | | | |

*Notes:* This table replicates the results in Table 3 on a subsample where $GovFinRD$ and $GBARD$ level and growth are jointly observed. standard errors are clustered by country, except for bootstrapped standard errors for LSDVC. Coefficient of $Gr(GDP)$, $Surplus$, $Debt$, and $Interest$ are scaled up with a factor of 100. The A-B estimates instrument the endogenous variable $y_{it-1} - y_{it-2}$ with the two-year lagged level of $y$, i.e. $y_{it-2}$. All other regressors are assumed to be strictly exogenous.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

**Table 10**
Arellano-Bond GMM estimates using alternative sets of instruments.

*Panel A:* $ln(GovFinRD)_{it}$

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| $Gr(GDP)_{it}$ | 0.293** | 0.258* | 0.432** | 0.253 | 0.339* | 0.439** | 0.374** | 0.424** |
| | (0.146) | (0.156) | (0.201) | (0.208) | (0.177) | (0.215) | (0.156) | (0.200) |
| $y_{it-1}$ | 0.905*** | 0.709*** | 0.838*** | 0.778*** | 0.771*** | 0.817*** | 0.838*** | 0.754*** |
| | (0.126) | (0.154) | (0.093) | (0.133) | (0.117) | (0.095) | (0.131) | (0.113) |
| N * T | 424 | 424 | 424 | 424 | 424 | 424 | 424 | 424 |
| N | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 |
| FE | YES | YES | YES | YES | YES | YES | YES | YES |
| Controls | YES | YES | YES | YES | YES | YES | YES | YES |
| Number of instruments | 28 | 50 | 322 | 50 | 73 | 301 | 50 | 72 |
| $y_{it-1}$ Instruments | | | | | | | | |
| First lag | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Last lag | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| $Gr(GDP)_{it}$ Instruments | | | | | | | | |
| First lag | – | – | 1 | 1 | 1 | 2 | 2 | 2 |
| Last lag | – | – | All | 1 | 2 | All | 2 | 3 |
| Hansen Test | 20.696 | 22.696 | 20.589 | 20.208 | 19.627 | 20.522 | 19.011 | 19.373 |
| ($p$-value) | (0.540) | (0.997) | (1.000) | (0.999) | (1.000) | (1.000) | (1.000) | (1.000) |
| A-B Test | | | | | | | | |
| AR(1) | −2.286 | −2.177 | −2.364 | −2.265 | −2.303 | −2.356 | −2.264 | −2.286 |
| ($p$-value) | (0.022) | (0.029) | (0.018) | (0.024) | (0.021) | (0.018) | (0.024) | (0.022) |
| AR(2) | 0.771 | 0.875 | 0.703 | 0.814 | 0.743 | 0.710 | 0.796 | 0.740 |
| ($p$-value) | (0.441) | (0.382) | (0.482) | (0.415) | (0.457) | (0.478) | (0.426) | (0.460) |

*Panel B:* $ln(GBARD)_{it}$

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| $Gr(GDP)_{it}$ | 0.328* | 0.365** | 0.379 | 0.373* | 0.410 | 0.364 | 0.457* | 0.497* |
| | (0.181) | (0.157) | (0.264) | (0.224) | (0.271) | (0.270) | (0.277) | (0.291) |
| $y_{it-1}$ | 0.840*** | 0.521*** | 0.861*** | 0.725*** | 0.668*** | 0.862*** | 0.743*** | 0.795*** |
| | (0.128) | (0.176) | (0.106) | (0.131) | (0.124) | (0.104) | (0.138) | (0.110) |
| N * T | 521 | 521 | 521 | 521 | 521 | 521 | 521 | 521 |
| N | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 |
| FE | YES | YES | YES | YES | YES | YES | YES | YES |
| Controls | YES | YES | YES | YES | YES | YES | YES | YES |
| Number of Instruments | 28 | 50 | 326 | 50 | 73 | 303 | 50 | 72 |
| $y_{it-1}$ Instruments | | | | | | | | |
| First lag | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Last lag | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| $Gr(GDP)_{it}$ Instruments | | | | | | | | |
| First lag | – | – | 1 | 1 | 1 | 2 | 2 | 2 |
| Last lag | – | – | All | 1 | 2 | All | 2 | 3 |
| Hansen Test | 22.847 | 24.910 | 26.385 | 26.686 | 27.308 | 26.328 | 26.359 | 27.529 |
| ($p$-value) | (0.410) | (0.991) | (1.000) | (0.982) | (1.000) | (1.000) | (0.984) | (1.000) |
| A-B Test | | | | | | | | |
| AR(1) | −3.165 | −2.047 | −3.356 | −2.936 | −2.843 | −3.368 | −2.906 | −3.276 |
| ($p$-value) | (0.002) | (0.041) | (0.001) | (0.003) | (0.004) | (0.001) | (0.004) | (0.001) |
| AR(2) | −1.147 | −0.814 | −1.188 | −1.082 | −1.057 | −1.192 | −1.090 | −1.132 |
| ($p$-value) | (0.251) | (0.416) | (0.235) | (0.279) | (0.290) | (0.233) | (0.276) | (0.257) |

*Notes:* This table provides variations of the A-B models in Table 3 regarding the correlation between GDP growth and the error term. Column (1) replicates the results reported in Table 3, using as instrument $y_{it-2}$ and for all other variables the instruments that result from the assumption that the variables are strictly exogenous. In column (2) we exploit more lagged levels of the dependent variable as instruments, i.e. we use $y_{it-2}$ and $y_{it-3}$ as instruments. Columns (3) to (8) relax the strict exogeneity of GDP growth. While columns (3) to (5) assume $Gr(GDP)_{it}$ to be predetermined, columns (6) to (8) allow it to be endogenous. While columns (3) and (6) use all instruments available under the respective assumption, the other estimates limit the number of lags included as instrument as indicated by "last lag" in order to reduce the problem of instrument proliferation. standard errors are clustered by country. Coefficients of $Gr(GDP)$ scaled up with a factor of 100. Regressions also include $Surplus_{it-1}$, $Debt_{it-1}$ and $Interest_{it-1}$.

* $p < 0.1$.

** $p < 0.05$.

*** $p < 0.01$.

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