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Abstract

We study the cyclicality of public R&D in 28 OECD countries (1995 – 2017). While procyclical on average, public R&D reacts asymmetrically over different phases of the business cycle and becomes acyclical during recessions. It is also heterogeneous across countries: Innovation leaders and followers behave countercyclically during recessions while moderate innovators behave procyclically. Furthermore, the share of public R&D allocated to the business sector is countercyclical, but the thematic composition remains stable. These results, not driven by countries' financial constraints, imply that countries behind the innovation frontier might strengthen their resilience to economic crises by adopting countercyclical R&D strategies.

Keywords: R&D, Public Policy, Business Cycle

JEL Classification: O38, H50, H12, E32

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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). Therefore, policymakers around the world strive to increase investment in R&D.[1] It is especially important to safeguard R&D during economic crises. During these crises, as demand shrinks, liquidity constraints tighten, and uncertainty rises, firms struggle to maintain their level of R&D investment (Bloom 2007, 2014; Himmelberg and Petersen 1994; Rafferty and Funk 2008), leading most firms to invest in R&D procyclically (Aghion et al. 2010; Barlevy 2007; Censolo and Colombo 2019; Fabrizio and Tsolmon 2014; Wälde and Woitek 2004). As business-cycle-induced reductions in private R&D spending jeopardize economies' long-term growth prospects, crises challenge governments to increase R&D, or at least to maintain current levels (Comin and Gertler 2006; Fatas 2000; Rafferty 2003). To the degree that public R&D can substitute for private R&D, governments can compensate for procyclical private R&D spending by implementing countercyclical public R&D spending programs (Alesina et al. 2008; Arreaza et al. 1999; Lane 2003) to support the private sector, or fund R&D in public research centres or universities. However, governments are constrained themselves by declining tax income and pressure to take measures for fiscal consolidation during crises, so they might decide to reduce public R&D expenditures as part of austerity measures. This paper investigates which of the opposing forces is stronger by asking whether 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, with a particular focus in how public R&D reacts to economic crises.

Few studies have addressed how public R&D responds to business cycles in general, or recessions in particular. An exception is Kim (2014), who analyses the cyclicality of government-financed R&D for different regimes of political economy for the pre-Great Recession period from 1981 to 2008. Kim finds countercyclicality in coordinated market economies and acyclicality in liberal and mixed market economies.[2] Studies that specifically address the Great Recession in 2008/09 find a wide range of policy responses: Comparing 2010 with the pre-crisis period 2006-2008, Makkonen (2013) finds that roughly half of the EU-27 countries reacted countercyclically and the other half procyclically. Izsak et al. (2013) extend this finding by showing that initially, in the period 2008-2010, most countries either countercyclically increased or acyclically maintained their public R&D spending, but many countries did not manage to maintain this spending level after 2010, during the debt crisis. Furthermore, drops in public R&D budgets seem proportional to

[1] For example, the European-wide growth strategy "Europe 2020" set a 3 percent R&D-to-GDP ratio as one of five key targets to achieve by 2020 (European Commission 2010). The US government's "A Strategy for American Innovation" considered R&D investment as key to US growth (White House 2015). In China, the 2006 "Medium- to Long-Term Plan for the Development of Science and Technology" committed to raising R&D spending to 2.5 percent of GDP by 2020 (Cao et al. 2006), and the 2015 plan "Made in China 2025" named fostering R&D in ten advanced industries and technologies as a key step to the country's becoming a leading manufacturer (State Council of the People's Republic of China 2015).

[2] 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.

general cuts in government expenditures (Makkonen 2013), except in innovation-leading countries in Europe (Veugelers 2014). However, these results are purely descriptive, do not control for other observed or unobserved country-level factors, and do not indicate the contingencies on which the policy responses might depend.

This study takes a broader perspective, beyond the Great Recession in 2008/09, to study econometrically the cyclicality of public R&D spending over a 20-year period, with a special interest in how public R&D reacts to economic crises. This approach allows us to answer the question concerning which of the opposing forces is stronger: the goal of increasing public R&D spending or the need for budgetary austerity. Our analysis, which is based on the Main Science and Technology Indicators (MSTI) database, considers 28 OECD countries from 1995 to 2017. 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. The advantage of using both indicators is that we can take a step forward by analyzing policy responses regarding the composition of public R&D in multiple dimensions. Government-financed R&D can be differentiated by whether the publicly financed R&D was carried out in the business enterprise sector, the higher education sector, or the government sector. We can make use of this feature to determine whether public R&D spending was directed more towards the business sector during economic crises. GBARD can be split based on socio-economic thematic areas, and we use this differentiation to determine whether GBARD focuses on different themes during crises (OECD 2015).

We make four contributions. First, we estimate the cyclicality of public R&D expenditures by relating them to real GDP growth. We control for other macroeconomic factors and use panel data estimators to account for country-specific unobserved variation. We find that, on average, public R&D is procyclical. A one percentage point decrease in GDP growth relates to a 0.44 percent drop in the level of government-financed R&D and a 0.35 percent drop in GBARD. The growth rates of government-financed R&D and GBARD decline by about 0.42 percentage points and 0.38 percentage points, respectively. Thus, on average, the pressure for fiscal consolidation is stronger during recessions than any concern about the long-term impact of falling R&D investments. However, such a spending pattern can lead to long-term losses in innovation and, by extension, in productivity, growth, and welfare (Aghion and Howitt 1992, 2009; Mohnen and Hall 2013).

Second, we study asymmetric behavior in government's R&D spending over the business cycle. Studies have documented asymmetries in private R&D and total government

[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.

spending,[4] In particular, we address whether the cyclicality of public R&D differs between phases of positive and negative GDP growth (Alesina et al. 2008). For instance, governments might deviate from their generally pro-cyclical 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. In other words, whereas public R&D budgets generally move with the economy, this pattern recedes during economic crises, an important nuance in the general finding of procyclicality.

Third, we investigate heterogeneous responses to business cycles in general and economic crises in particular. Reports on policy responses to the 2008/09 Great Recession suggest heterogeneous responses, as some countries maintained existing or implemented new public R&D programs, while others cut back on public R&D (Izsak et al. 2013; OECD 2012). More specifically, we study the role of two contingencies that could influence the cyclicality of the government's R&D response: the country's innovation performance as an indicator of the importance of innovation in the economy, and the level of public debt as a measure for financing constraints. We show that, over the whole business cycle, European innovation leaders and highly innovative non-European countries set acyclical public R&D policies, whereas moderate innovators and innovation followers behave procyclically.[6] We also combine asymmetric and heterogenous responses and investigate, for example, whether stronger innovators made stronger changes to their strategies during economic crises, compared to other periods, than weaker innovators. Our results show that the acyclicality observed among leading innovators over the whole business cycle is driven by a strongly differentiated public R&D strategy: outside of recessions, R&D spending is procyclical. During recessions, spending becomes strongly countercyclical. The same pattern is found for innovation followers, while moderate innovators behave procyclically over the entire business cycle. Thus, the cyclicality of public R&D spending varies based on countries' innovation performance and the business cycle. Strong innovators differentiate themselves through a countercyclical spending strategy during recessions, a difference that may widen the gap between strong and weak European innovators and contribute to intra-European differences in income. In addition, our results show that the cyclicality of public R&D spending is contingent on the level of public debt. To the extent that they have less access to credit markets, governments that carry high public debt might face more difficulties finding financing for countercylical R&D spending (Alesina et al. 2008). Our results support this conjecture by showing that public R&D spending is more procyclical in high-debt countries, but only outside of recession periods. During recessions, public R&D spending turns acyclical regardless of public debt levels.

[4] Private R&D behaves asymmetrically over the business cycle (Rafferty 2003), and responds asymmetrically to positive and negative demand shocks (Ouyang 2011). 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] We use the European Scoreboard to define innovation leaders, innovation followers and moderate innovators, see section 3 for more details.

Fourth, we investigate whether business cycles and recessions induce changes in where public R&D is spent in terms of sectors and in terms of socio-economic objectives. We show that countries, on average, allocate a stable share of government-financed R&D expenditures to the business sector (at the expense of government institutes or universities) that is independent of the business cycle. An exception are innovation followers that implement a countercyclical increase in the share of R&D assigned to the business sector during recessions. We also find that the thematic composition of public R&D remains stable throughout the business cycle. In particular, we do not find that more R&D is assigned to domains that are most likely to lead to direct economic growth during recessions, especially to R&D related to economic development.

The remainder of this paper is structured as follows. Section 2 discusses how business cycles, particularly economic recessions, may influence private and public R&D expenditures. 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

2.1 Cyclicality of private R&D investment

Shifts in opportunity costs, liquidity constraints, demand for innovations, and uncertainty are the main reasons that business cycles affect privately financed R&D investment. These factors have opposing effects. Recessions lower the opportunity costs – in terms of foregone profits – of shifting resources to long-term investments and should lead to more private R&D (Aghion and Saint-Paul 1998; Saint-Paul 1993). After the recession, firms can benefit from these investments to meet new demand at higher productivity levels (Aghion and Saint-Paul 1998). Thus, shifts in opportunity costs create countercyclical private R&D investment.

On the other side, recessions reduce the financial resources firms have for R&D. Firms primarily need to finance R&D from cash flow because of credit market imperfections (Himmelberg and Petersen 1994; Hottenrott et al. 2016). However, as demand falls in recessions, cash flows also shrink. These increased financial constraints make it difficult to maintain, much less increase, R&D investment, leading to procyclical private R&D investment.

Low demand during recessions also impacts firm's incentives to perform R&D (Schleifer 1986; Schmookler 1966). The successful introduction of high-quality innovations generally requires users to be willing to pay more than they did for older products. This willingness is usually higher during periods of market expansions, when budget restrictions are not as tight as during recession periods. To avoid bringing to the market new products that will face low demand, firms will postpone some of their R&D programs during recessions to align new product launches with a favorable market environment, leading to procyclical private R&D investment (Rafferty and Funk 2004).[7]

Recessions are also typically periods of high uncertainty. Bloom (2007) shows that uncertainty in recessions leads firms to delay decisions about adjustments to R&D investment, which helps to explain why R&D is more persistent than other investments, but also that firms will be less responsive to R&D policy measures during recessions.

Most empirical evidence shows that private R&D investment is procyclical, supporting the arguments related to liquidity constraints and demand shock. Wälde and Woitek (2004) find procyclical private R&D investment among G7 countries between 1973 and 2000, and Barlevy (2007) concludes the same using U.S. National Science Foundation (NSF) and Compustat data for 1958-2003.[8] Barlevy builds a Schumpeterian endogenous growth model that predicts that R&D fluctuates procyclically even though the model's socially optimal R&D path is countercyclical, arguing that this result is due to dynamic externalities: Firms are afraid of being imitated quickly, so they shift both R&D and their innovations' implementation to boom periods during which gains from innovations are larger. Fabrizio and Tsolmon (2014) find support for these predictions in U.S. data (1975-2002), showing that the procyclicality of R&D is stronger in industries that have a fast technological pace, where innovations become obsolescent quickly.[9] Paunov (2012) also reports a procyclical pattern of private R&D investment for the Great Recession in 2008/09, showing that many Latin American firms stopped ongoing innovation projects in the wake of the crisis.

Evidence of heterogenous responses in private R&D spending is most prominently provided by Aghion et al. (2012), who show that credit constraints affect the cyclicality of private R&D. Using a sample of 13,000 French firms between 1993 and 2004, they find that firms that have no credit constraints invest countercyclically, but credit-constrained firms invest more procyclically as credit constraints tighten.[10] An even more nuanced result on the procyclicality of R&D that is caused by financial constraints is provided by Aghion et al. (2010), whose analysis of 21 OECD countries over a 40-year period reveals procyclical long-term investment patterns in countries with tight credit constraints.[11] This is not only because credit constraints limit the ability to invest, but also because they increase the

[7]Francois and Lloyd-Ellis (2003, 2009) investigate the timing of the market introduction of innovations over the business cycle, taking into account that innovation is a multi-stage process: the R&D phase in order to create ideas, the commercialization phase to search for a concrete application (product) using the idea, and the implementation phase. Their model predicts the R&D phase and the implementation phase to be procyclical, whereas commercialization efforts are countercyclical.

[8]For further empirical evidence on procyclicality of R&D investment in the U.S. using NSF data, see Fatas (2000), Rafferty (2003), Comin and Gertler (2006), and Ouyang (2011). While Fatas uses total R&D expenditures, the other studies rely on private-sector R&D spending.

[9]Fabrizio and Tsolmon (2014) test similar models developed by Shleifer (1986) and Francois and Lloyd-Ellis (2003). In contrast to Barlevy (2007), Shleifer's model considers only the timing of innovation while Francois and Lloyd-Ellis' model separates the timing of innovative effort from the innovation's implementation.

[10]Bovha Padilla et al. (2009) and López-García et al. (2013) employ a similar approach as Aghion et al. (2012) using Slovenian and Spanish firm-level data, respectively. Both studies corroborate the countercyclicality of R&D among unconstrained firms.

[11]Aghion et al. (2010) do not use R&D investment but the share of long-term investment to total investment as a proxy for growth-enhancing investment.

probability that long-term investment will be interrupted by a liquidity shock that reduces the ex-ante incentive to invest, which is especially the case during in recessions. Evidence for significant heterogeneity across countries is also provided by Censolo and Colombo (2019), whose results show countercyclicality of private R&D investment in the EU's core countries but not its periphery countries.

A few studies have also documented asymmetric responses in private R&D spending. Ouyang (2011) finds that private R&D investment responds asymmetrically to demand shocks. Using U.S. sector data between 1958 and 1998, she finds R&D to be generally procyclical. However, demand shocks have asymmetric effects. A demand shock that raises output reduces R&D because of higher opportunity costs (countercyclical effect in booms), while a demand shock that reduces output also reduces R&D because lower demand reduces the firm's net worth, leading to stronger financial constraints which outweigh lower opportunity costs (procyclical effect in recessions). Studying asymmetries in private R&D over the business cycle, Rafferty and Funk (2008) show that the effects of positive and negative changes in cash flow on R&D differ, as an increase in cash flow has a smaller effect on private R&D than a decrease in cash flow.

2.2 Cyclicality of public R&D investment

In contrast to the number of studies on private R&D, few studies have analyzed the cyclicality of public R&D investment, even though more than a quarter of total gross expenditure on R&D (GERD) in OECD countries is publicly financed.[12] This kind of expenditure attracted substantial policy attention in these countries after the Great Recession in 2008/09 (European Commission 2011; OECD 2009, 2012). The main question is whether governments increase or decrease public R&D budgets during a recession.

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 a neoclassical perspective, the government reaction depends on the degree of substitutability between government and private spending. Public spending should be countercyclical if private R&D is procyclical and they are substitutes (Alesina et al. 2008; Arreaza et al. 1999; Lane 2003).

However, similar to private R&D, public spending could also be procyclical because of a liquidity effect. 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

[12] In 2017, the percentage of GERD financed by the government was 25.1% in the OECD and even 29.7% in the EU-28 (OECD 2020).

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. The second argument for a procyclical pattern of public R&D is the voracity effect (Tornell and Lane 1999), which suggests that, in countries without strong budgetary institutions and coordination mechanisms that facilitate internalizing costs that are associated with public expenditures, government spending is higher and government surplus is lower during an economic upturn (Raudla 2010). The argument for this effect is that competing blocs like branches of government, parties, ministries, and other political actors each expect the others to demand a higher share of the increasing government income. As a result, these groups have a low incentive to act prudently: Not appropriating more does not lead to lower government expenditures but to higher appropriation by the other groups (Lane 2003).[13]

Some studies have looked at the cyclicality of government spending in general. Abbott and Jones (2011) show that aggregate government spending in a panel of OECD countries is acyclical. However, they also document procyclical spending – and, thus, voracity effects – in certain budget categories, indicating that the voracity effect seems to be a function of the political pressure in a given budget and the risk-aversion of policy makers. Lane (2003) also studies OECD countries and finds heterogenous effects in the sense that government spending is more procyclical in countries with more volatile output and more dispersed political power, which is in line with the voracity effect. Similarly, Talvi and Végh (2005) find evidence for voracity effects and, thus, procyclicality in fiscal policy among developing countries, but acyclical fiscal policy among G7 countries. They argue that this difference is due to the much greater fluctuations in developing countries' tax bases than in G7 countries.[14] Woo (2009) provides evidence that more inequal countries in terms of income and education tend to show more procyclical public spending. Overall, the results document heterogeneity in the responses to recessions in terms of government spending.

The empirical evidence on the cyclicality of public R&D is still scarce. A few studies have addressed public R&D during the Great Recession of 2008/09.[15] For example, Makkonen (2013), who compares GBARD data for the EU-27 countries in 2010 with those for 2006-

[13] Alesina et al. (2008) propose a theory that is similar and complementary to the voracity effect, where voters demand more public goods or lower taxes during economic expansion to reduce rents by corrupt governments. They refer to this theory as "starving the Leviathan" (p.1) and show that fiscal policy is more procyclical in more corrupt democracies. Similar to our approach, Alesina et al. (2008) consider asymmetries in cyclicalities between booms and recessions.

[14] Full tax-smoothing would then mean that governments run large surpluses during expansionary periods and large deficits during contractions. Following the voracity argument, large budget surpluses create political pressure for more government spending. If governments fold under this pressure, they spend the surplus instead of using it to reduce debt or the tax burden. Talvi and Végh (2005) show that, under these circumstances, it is optimal to lower tax rates during expansions to reduce political spending pressure, but not by so much that an increase in spending is fully offset by the intertemporal distortions of lower tax rates that have to be taken into account. Thus, procyclical government spending is optimal for countries with large tax fluctuations.

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

2008, finds evidence for both counter- and procyclical behavior, each in about half of the countries. However, Makkonen's comparison of R&D budget categories according to socio-economic objectives reveals that three-quarters of the countries cut R&D budgets in more categories during the crisis than they did in the pre-crisis period and interprets this as strong evidence of procyclicality. Furthermore, the cut in R&D budgets seems roughly proportional to the general slowdown in government spending during the crisis. In a study prepared for the European Commission, Izsak et al. (2013) also examine the effect of the 2008 Great Recession on public R&D in EU member states using GBARD and data on governments' R&D funding programs. While they find that, in the initial 2008-2010 period, most countries either countercyclically increased or acyclically maintained their public R&D, some countries found it difficult to maintain funding levels in the following years. They also report a slight movement toward more targeted policies; in particular, countries strengthened their innovation policies in green technology and information technologies like broadband infrastructure and high-speed communication. Others countries tried to make public funding more efficient by reinforcing public-private R&D partnerships, particularly in energy, the environment and health. A study by the OECD drew similar conclusions for a larger set of OECD countries, as most of them did not cut their public R&D budgets in 2009, the most severe year of the 2008/09 Great Recession. Despite this general resilience, policy responses differed substantially, ranging from implementing recovery policies that mainly supported ongoing innovation policy initiatives to policies that deliberately avoided changes in R&D spending levels and uncertainty about long-term priorities and safeguard continuity, to implementing new public R&D programs that typically focused on firm's access to credit and venture capital, adjusting R&D tax incentive schemes, and setting thematic priorities in areas deemed critical for competitiveness and public welfare (OECD 2012).

Overall, these purely descriptive results document a wide range of policy responses but leave open a set of important questions that we address in this paper: First, to what extent do the results on the cyclicality of public R&D hold when we control for other observed or unobserved country-level factors? Second, does public R&D react asymmetrically to positive and negative growth of GDP? Building on the results for private R&D, we investigate whether public R&D responds differently to expansion than to contraction. Third, what conditions or circumstances determine governments' responses related to public R&D? While previous studies descriptively document heterogeneity in the cyclicality of public R&D, only Kim (2014) addresses these conditions by investigating whether the nature of coordination between private and public sector organizations affect governments' R&D responses. Based on a multivariate analysis of 21 OECD countries for the pre-Great-Recession period between 1981 and 2008, Kim finds that public R&D is countercyclical among coordinated market economies but acyclical among liberal and mixed market economies. This finding is in line with the "varieties of capitalism" theory: In coordinated market economies, governments are more willing to compensate for falling private R&D because they find it easier to prevent the opportunistic behavior of firms that would occur if the firms cut private R&D in anticipation of increasing public R&D. The present paper addresses the role of two other potential contingencies that could influence the cyclicality of public R&D spending: the country's innovation performance and the level of public debt. In particular, we investigate whether countries that are considered leading innovators, and that presumably consider innovation-driven growth as a higher priority than others do, reflect this priority through countercyclical public R&D spending during recessions. Finally, we investigate whether there is a general pattern of business cycles' and recessions' inducing significant changes in priorities concerning where public R&D is spent in terms of both sectors and socio-economic objectives.

3 Data and Econometric Model

Our empirical analysis is based on the MSTI database (version 2018/2) provided by the OECD (2019). The MSTI database contains information on public R&D expenditures from 1981 to 2017, 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 2017. The sample is an unbalanced panel of 28 countries with an average of 17.1 yearly observations per country, ranging from 3 to 23 observations. Table 7 in the appendix provides the list of included countries, how often and for which time period each country is observed, and each country's distribution over the business cycle phases.

The MSTI database provides two indicators of publicly financed R&D expenditures: GBARD ($GBARD$) 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 using performer-based reporting with the measure derived 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.[16] 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.[17,18] However, governments might deviate from their intended budget plans because of, for instance, unexpected short-term economic fluctua-

[16] 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).

[17] 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).

[18] 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.

tions. 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.[19] While they are included in GBARD, government-financed R&D covers only publicly financed domestic R&D activities.

$GBARD$ is are directly observed in the data, while $GovFinRD$ is calculated as the reported share of 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:

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

Here, y_{it} is either $ln(GBARD)$ or $ln(GovFinRD)$, α_i is a country fixed effect that captures unobserved heterogeneity across countries, and ϵ_{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 equation (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.

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

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.

In the empirical analysis, 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 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 either the country's innovation performance or its debt level (as a % of GDP). To measure the country's innovation performance, we use the European Innovation Scoreboard (EIS) classification of the country's innovation status and categorize the European countries into innovation leaders (L), innovation followers (F), moderate innovators (M), and modest innovators. (As there are few modest innovators, we group the last two groups into moderate innovators). In addition, our sample contains a group of highly innovative non-EU countries (N), which we treat as a separate group to identify whether European and non-European innovation-leading countries differ in their choice of a public R&D strategy to combat economic crises.[20] Table 7 in the appendix provides the innovation status for each country and Table 8 the distribution of the innovation status by business cycle phase.

Third, we investigate whether governments respond to economic crises with shifts in their allocation of public R&D spending according to themes and beneficiaries. GBARD can be broadly split by socio-economic thematic areas into defence and civil R&D, with civil R&D further broken down into six categories.[21] Government-financed R&D can be split by whether the beneficiary is the business sector or the public sector (government and higher education). We estimate model (1) separately for each subgroup while simultaneously allowing for heterogeneous and asymmetric effects of $Gr(GDP)_{it}$.

Table 2 contains basic summary statistics. On average, GDP has been growing at the rate of 2.69 percent per annum. Public R&D growth is of a similar order of magnitude, at about 2.44 percent for $GBARD$ and 2.53 percent for $GovFinRD$. In addition, Table 9 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. Figure 3 in the appendix shows the evolution of public R&D growth over time. While we observe only small differences in the growth of $GovFinRD$ and $GBARD$ up to the 2008/09 recession, deviations increased afterward. Figure 4 in the appendix shows a slight

[20] Non-European countries in our analysis are Switzerland (1st among non-EU countries/1st overall), the United States (2/3), Israel (4/10), Japan (8/15), Canada (9/17) and Australia (12/22), all of which can be considered highly innovative. In brackets is their ranking in the 2019 Global Innovation Index (Cornell University et al. 2019).

[21] For more details on civil R&D's six categories, see section 4.4.1.

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
$Gr(GovFinRD)$	Year-over-year natural growth rate of $GovFinRD$	%	OECD MSTI
$Gr(GBARD)$	Year-over-year natural growth rate of $GBARD$	%	OECD MSTI
GDP	Gross Domestic Product	Million PPP $[a]	OECD[b]
$Gr(GDP)$	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[b]
$Debt$	Government debt	% of GDP	OECD[b]
$Interest$	Long-term interest rate	% per annum	OECD[b]
L, F, M, N	Country's innovation performance. According to the country's ranking in the European Innovation Scoreboard, we distinguish European countries into leading innovators (L), innovation followers (F), and moderate innovators (including modest innovators, as there are few observations in this group) (M). Highly-innovative non-EU countries are included as separate group N.	Categorical	European Innovation Scoreboard[c]

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]OECD national account data, https://stats.oecd.org, downloaded 16.07.2019. [c] 2016 edition; cf. Hollanders et al. (2016).

Table 2: Summary statistics

	N	Mean	S.D.	p10	p50	p90
$ln(GovFinRD)$	448	7.978	1.624	5.742	7.723	9.946
$ln(GBARD)$	524	8.019	1.575	5.834	7.887	9.898
$Gr(GovFinRD)$	402	2.530	8.110	−5.791	1.912	12.313
$Gr(GBARD)$	511	2.443	7.952	−5.934	1.860	12.171
$Gr(GDP)$	530	2.685	2.994	−0.714	2.825	5.819
$ln(GDP)$	530	13.180	1.362	11.428	12.837	14.789
$Surplus$	530	−2.790	3.518	−7.019	−2.610	1.019
$Debt$	530	79.144	38.749	38.906	71.033	126.899
$Interest$	530	4.273	2.412	1.149	4.290	6.855
$Recession$	530	0.132				
L	530	0.172				
F	530	0.289				
M	530	0.338				
N	530	0.202				

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. In order to not remove relevant differences across business cycle stages and innovation status, this was done separately for each business cycle stage - innovation status combination.

falling trend between 1995 and 2005, increases between 2005 and 2009, and decreases again after 2009 in the evolution of the share of GDP spent on public R&D. We provide more descriptive evidence of the evolution of public R&D by business cycle in section 4.1 below.

4 Results

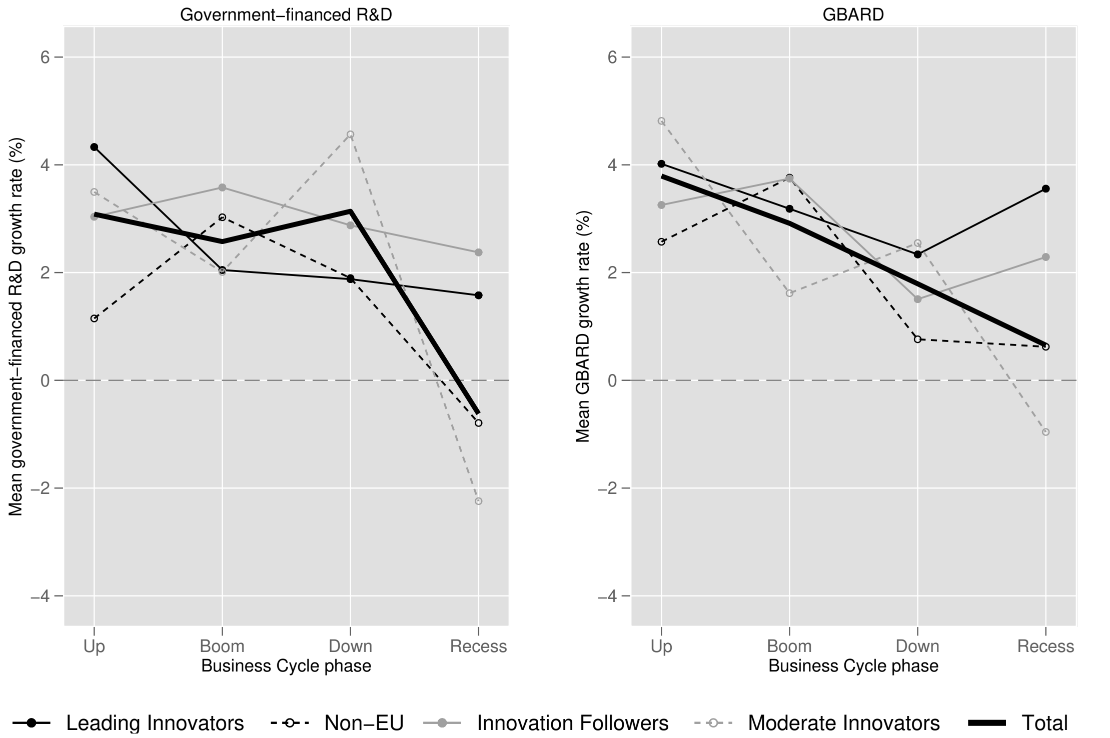
We start our empirical analysis with a description of public R&D expenditures over the business cycle in subsection 4.1. Subsection 4.2 presents results for our benchmark model on the average cyclicality of public R&D, and subsection 4.3 investigates asymmetry and heterogeneity in the cyclicality of public R&D responses. Finally, subsection 4.4 provides evidence on the allocation of public R&D by theme and beneficiary over the business cycle.

4.1 Descriptive evidence on the cyclicality of public R&D

Figure 1 presents the average growth rate of public R&D - government-financed R&D, $Gr(GovFinRD)$, and GBARD, $Gr(GBARD)$ over the business cycle for our total sample and separately for each country group (leading innovators, innovation followers, moderate innovators, non-EU countries). For the total sample, the two types of public R&D have similar patterns. The average growth rate of $Gr(GovFinRD)$ shows only a little variation in upturn, boom, and downturn periods, but it falls steeply in a recession, suggesting procyclicality. The average growth rate of $Gr(GBARD)$ seems to be more responsive to changes in business cycles, as it drops in economic downturns, rather than only in recessions. However, the overall mean disguises considerable variation in public R&D responses across the four groups. For non-EU countries and moderate innovators, the pattern in

$Gr(GovFinRD)$ is clearly procyclical: growth is negative during recession phases, and positive over the rest of the business cycle. Leading innovators and innovation followers also show slightly lower $Gr(GovFinRD)$ in recessions than in the rest of the business cycle, but they maintain comparatively high positive growth rates. This pattern is similar for $Gr(GBARD)$, but here innovation leaders and innovation followers show an uptick during recessions, compared to downturns.

Figure 1: Mean growth rates of public R&D expenditures (%) over the business cycle

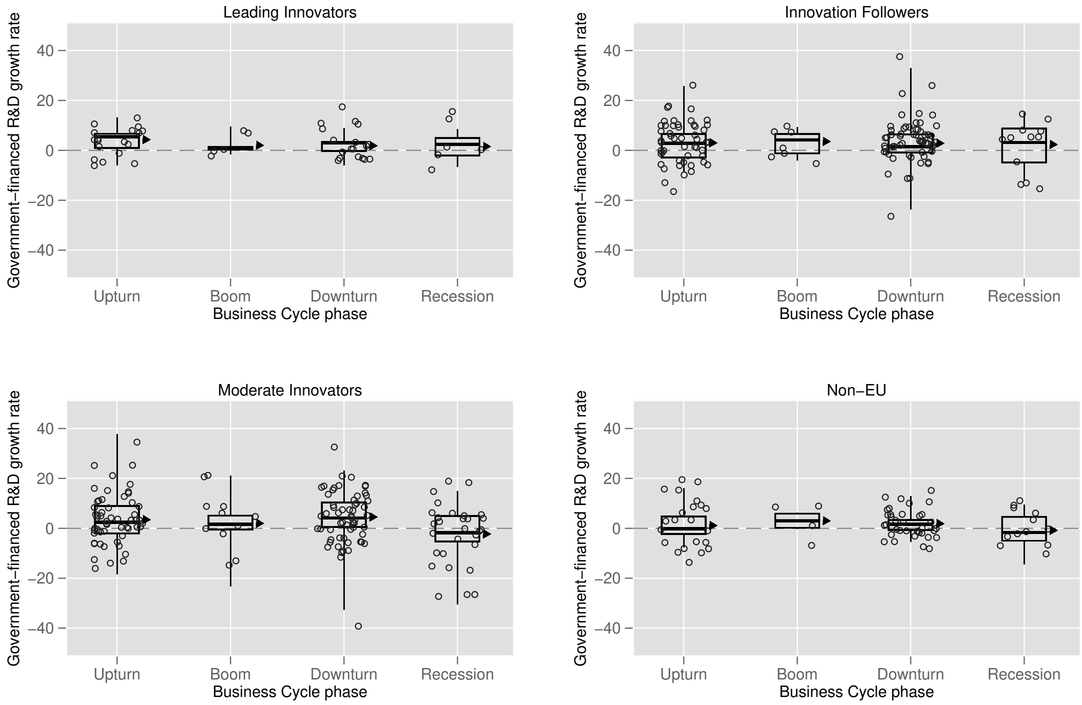


Notes: Recessions (Recess) are defined as periods of negative GDP growth: $Gr(GDP)_{it} < 0$ (cf. Table 1). Upturns (Up) are periods of positive and increasing GDP growth, while downturns (Down) describe periods of positive but decreasing GDP growth. Boom periods are defined as the final year of increasing GDP growth before growth decreases.

Figure 2 broadens the picture on country differences by showing the distribution of $GovFinRD$ over the business cycle for the same four groups. While Figure 1 shows average growth rates, Figure 2 presents the spread of growth rates within each group. For leading innovators and highly innovative non-EU countries, patterns are broadly comparable and the spreads are relatively narrow. For innovation followers, the spread is larger during upturns and downturns, but for moderate innovators, the spread is wide over the whole business cycle, with R&D cuts up to -40 percent.

However, Figure 1 does not control for any other observed or unobserved country-level factors. To do so and to properly identify the cyclicality of public R&D, we estimate the benchmark model and its extensions in the following subsections.

Figure 2: Distribution of government-financed public R&D growth over the business cycle



Notes: The graphs show the growth rate of government-financed R&D, $Gr(GovFinRD)$, across country groups and phases of the business cycle. The horizontal lines indicate the first quartile, median, and third quartile of the distribution within each country group and business cycle phase. The whiskers indicate the 1st and 99th percentiles, and the triangle shows the mean growth rate. See Figure 5 in the appendix for the equivalent figure for $Gr(GBARD)$. See Figure 1 for additional notes.

4.2 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), which controls for country fixed effects and employs a fixed effects (FE) estimator; model (3), which employs a first difference (FD) estimator; model (4) and model (6), which add dynamics and employ Arellano and Bond's (1991) GMM estimator (A-B) for $ln(GovFinRD)$ and $ln(GBARD)$, respectively; and model (5) and (7), which 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)

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

y_t	Level							Growth		
	$ln(GovFinRD)_t$					$ln(GBARD)_t$		$Gr(GovFinRD)_t$		$Gr(GBARD)_t$
	(1) OLS	(2) FE	(3) FD	(4) A-B	(5) LSDVC	(6) A-B	(7) LSDVC	(8) OLS	(9) OLS	(10) OLS
$Gr(GDP)_t$	-0.246	0.286	0.432**	0.216	0.441***	0.326*	0.351**	0.474***	0.422***	0.381**
	(0.696)	(0.307)	(0.177)	(0.165)	(0.139)	(0.178)	(0.146)	(0.154)	(0.138)	(0.150)
$ln(GDP)_{t-1}$	1.121***	1.436***	0.711**	0.554**	0.181***	0.511*	0.082	0.003	0.003	0.000
	(0.045)	(0.116)	(0.263)	(0.240)	(0.054)	(0.273)	(0.051)	(0.003)	(0.002)	(0.002)
$Surplus_{t-1}$	1.564	-0.499	-0.145	-0.223	0.326**	0.151	0.549***	0.387**	0.335**	0.531***
	(1.152)	(0.437)	(0.252)	(0.396)	(0.158)	(0.633)	(0.158)	(0.147)	(0.121)	(0.093)
$Debt_{t-1}$	-0.068	-0.021	-0.104	-0.099	-0.071**	-0.133*	-0.043	-0.018	-0.012	0.005
	(0.107)	(0.108)	(0.100)	(0.088)	(0.028)	(0.071)	(0.027)	(0.016)	(0.015)	(0.011)
$Interest_{t-1}$	-2.127*	1.216*	-0.219	0.332	0.429	0.216	0.166	0.189	0.261	0.280
	(1.091)	(0.712)	(0.393)	(0.547)	(0.284)	(0.633)	(0.320)	(0.350)	(0.284)	(0.303)
y_{it-1}				0.611**	0.925***	0.552**	0.933***		0.181*	0.122***
				(0.245)	(0.028)	(0.261)	(0.029)		(0.092)	(0.041)
Constant	-6.579***	-11.007***	0.009					-0.004	-0.014	0.010
	(0.673)	(1.547)	(0.009)					(0.042)	(0.038)	(0.028)
FE	NO	YES	YES	YES	YES	YES	YES	NO	NO	NO
N * T	417	417	356	351	379	448	481	380	373	475
R^2	0.958	0.710	0.072					0.081	0.102	0.103
Hansen Test				19.431		22.133				
(p-value)				(0.997)		(0.990)				
A-B Test										
AR(1)				-1.662		-1.631				
(p-value)				(0.096)		(0.103)				
AR(2)				0.888		-1.060				
(p-value)				(0.375)		(0.289)				

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. *** p<0.01, ** p<0.05, * p<0.1. Coefficients of $Gr(GDP)$, $Surplus_{t-1}$, $Debt_{t-1}$, and $Interest_{t-1}$ 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 10 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 two lagged levels of y, (i.e. y_{it-2} and y_{it-3}). All other regressors are assumed to be strictly exogenous. See Table 11 in the appendix for alternative specifications that allow $Gr(GDP)$ to be predetermined or endogenous.

(-0.246) is negative but not statistically significant. In model (2), the coefficient of GDP growth reverses, turning positive, but is still insignificant at 0.286. 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. Procyclicality holds across the remaining specifications, at different levels of statistical significance. 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 0.432 ($p < 0.05$). Finally, in our preferred specifications for log-levels, we also account for dynamics in public R&D expenditures in models (4), (5), (6), and (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 also estimate the dynamic model using the LSDVC estimator. One downside to this approach is that, while the A-B estimator allows for endogenous regressors, the LSDVC estimator requires strictly exogenous regressors. The A-B estimates confirm consistency, as both 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 ($p > 0.10$).[22] Regarding the coefficient of GDP growth, the results confirm that public R&D expenditure is procyclical. The A-B estimates show a positive but not significant impact of about 0.216 on $ln(GovFinRD)$. This effect is slightly larger and weakly significant in the estimate of the cyclicality of $ln(GBARD)$ in model (6) (0.326, $p < 0.10$). The LSDVC results are higher with a coefficient of 0.441 and 0.351 for $ln(GovFinRD)$ and $ln(GBARD)$ in models (5) and (7), respectively. Both estimates are significant at the 1% and 5% levels, respectively. In summary, and taking the LSDVC specifications as our preferred models, we conclude that a one percentage point decrease in GDP growth relates to a 0.44 percent decrease in government-financed R&D and a 0.35 percent decrease 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 without fixed effects (model (9)) for $Gr(GovFinRD)$, while model (10) compares the dynamic results using $Gr(GBARD)$ as the outcome variable.[23] The same pattern emerges from the estimates across all three of these models: The coefficient of GDP growth is significantly positive, confirming the *procyclicality* of public R&D. However, note that the interpretation of the coefficient of our focus variable changes from a semi-elasticity between GDP growth and the level of spending to a unit change relationship between GDP growth and the growth of public R&D. That is, based on models (8), (9), and (10), we conclude that a one percentage point decrease in the growth rate of GDP co-occurs with a 0.42 percentage point decline in the growth rate of $GovFinRD$ ($p < 0.01$) and a 0.38 percentage point decline in the growth rate of $GBARD$ ($p < 0.05$).

[22] For the A-B estimates, we instrument the endogenous variable $y_{it-1} - y_{it-2}$ with up to two lagged levels of y (i.e. y_{it-2} and y_{it-3}). All other regressors are assumed to be strictly exogenous to reduce the number of instruments and the problem of instrument proliferation, given the small number of countries (N). Table 11 in the appendix shows that the estimated coefficients are similar in size but less precisely estimated when we increase the number of instruments by allowing $Gr(GDP)$ to be predetermined or endogenous as well.

[23] 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. As the specification does not include country fixed effects, it is not necessary to instrument the dynamic term, although doing so does not critically affect the estimated coefficients.

Our result of procyclicality is in line with the liquidity effect and voracity effect arguments discussed in section 2. On average, the pressure for fiscal consolidation is stronger during recessions than is any concern about the long-term impact of declining R&D investment. In section 4.3, we further investigate to what extent the liquidity effect drives this result by examining heterogeneity across countries whose levels of public debt differ.

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 all dynamic specifications. Thus, persistence holds for both the level of public R&D expenditure and its growth rate. 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 positive related to government budget surplus. Public debt has the expected negative coefficient in most regressions, but it is significant only in the A-B estimates for $ln(GBARD)$. No clear pattern emerges for long-term interest rates.

4.3 Asymmetry and heterogeneity in the cyclicality of public R&D

The results in section 4.2 show that, on average, public R&D expenditures and government budgets for R&D behave procyclically. This result suggests that, on the whole, fiscal and political pressure for consolidation dominate the expected benefits of public R&D spending. However, the descriptive analyses in Figures 1 and 2 point toward asymmetric behavior during recession periods compared to non-recession periods and also reveal substantial heterogeneity based on a country's innovation status. Leading innovators and innovation followers in particular seem to deviate in recession periods, suggesting that those countries might implement a countercyclical public R&D policy during recessions. In addition, cyclicalities might differ in countries with higher and lower debt levels, as governments with high debt face a stronger need for fiscal consolidation during recession since they have less access to credit markets (Alesina et al. 2008).[24]

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 debt level, and the combination thereof. In each specification, we interact dummies for innovation status, debt level, 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 4 shows the results for the growth in public R&D expenditures, which are largely

[24] This argument relates to the findings of Aghion et al. (2010, 2012) for the private sector, where credit constraints determine whether firms can invest countercyclically during economic downturns.

in line with the patterns documented in Figures 1 and 2. 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. 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 based on countries' innovation status are also addressed in models (2) and (5) of Table 4. Most of the average procyclicality documented in Table 3 seems to be driven by moderate innovators and only somewhat by innovation followers. The coefficient of GDP growth is positive and significant for both groups, although the coefficient of moderate innovators is more than three times that of innovation followers. In contrast, European and non-European 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 the cyclicality of public R&D is contingent on a country's innovation performance.

Table 4: Effect of business cycles on public R&D expenditures, by country innovation status and business cycle phase

y_t	$Gr(GovFinRD)_t$			$Gr(GBARD)_t$		
	(1) OLS	(2) OLS	(3) OLS	(4) OLS	(5) OLS	(6) OLS
$Gr(GDP)_t$ × No rec	0.462**			0.568**		
	(0.215)			(0.242)		
$Gr(GDP)_t$ × Rec	0.286			-0.159		
	(0.459)			(0.524)		
$Gr(GDP)_t$ × L		0.248			0.147	
		(0.195)			(0.148)	
$Gr(GDP)_t$ × F		0.185*			0.222*	
		(0.093)			(0.127)	
$Gr(GDP)_t$ × M		0.739***			0.747**	
		(0.135)			(0.278)	
$Gr(GDP)_t$ × N		0.210			0.168	
		(0.189)			(0.183)	
$Gr(GDP)_t$ × L × No rec			0.436*			0.407*
			(0.247)			(0.216)
$Gr(GDP)_t$ × L × Rec			-0.410*			-0.561*
			(0.210)			(0.327)
$Gr(GDP)_t$ × F × No rec			0.311**			0.457**
			(0.126)			(0.177)
$Gr(GDP)_t$ × F × Rec			-0.940**			-1.371*
			(0.439)			(0.679)
$Gr(GDP)_t$ × M × No rec			0.796***			0.958**
			(0.242)			(0.399)
$Gr(GDP)_t$ × M × Rec			0.791*			0.459
			(0.386)			(0.510)
$Gr(GDP)_t$ × N × No rec			0.270			0.382*
			(0.260)			(0.217)
$Gr(GDP)_t$ × N × Rec			0.347			-0.440
			(1.091)			(1.151)
$ln(GDP)_{t-1}$	0.001	0.002	0.001	0.000	0.001	0.000
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$Surplus_{t-1}$	0.336**	0.355***	0.336**	0.540***	0.575***	0.568***
	(0.124)	(0.117)	(0.120)	(0.094)	(0.105)	(0.108)
$Debt_{t-1}$	-0.011	-0.007	-0.004	0.007	0.007	0.011
	(0.015)	(0.015)	(0.015)	(0.011)	(0.010)	(0.010)
$Interest_{t-1}$	0.227	0.200	0.208	0.268	0.270	0.259
	(0.271)	(0.265)	(0.245)	(0.276)	(0.272)	(0.269)
y_{t-1}	0.179*	0.169*	0.165*	0.124***	0.104**	0.101**
	(0.091)	(0.089)	(0.091)	(0.041)	(0.045)	(0.044)
N * T	373	373	373	475	475	475
R^2	0.194	0.208	0.216	0.198	0.206	0.222

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. N: non-EU countries. Rec and No rec indicate recession and non-recession periods, respectively. Standard errors are clustered by country. *** p<0.01, ** p<0.05, * p<0.1. For additional notes, see Table 3.

Table 4 also shows the combined effect of heterogeneity based on the countries' innovation status and of asymmetry by recession period in models (3) and (6). Leading innovators and innovation followers (and to some extent also innovation leaders outside of Europe) differ from moderate innovators by differentiating their public R&D strategies between recession and non-recession periods. For innovation leaders' government-financed R&D, the coefficient of $Gr(GDP)$ is estimated to be *procyclical* outside of recession periods (0.436, $p < 0.10$) but *countercyclical* during recessions (-0.410, $p < 0.10$). The same can be observed in the growth of $GBARD$ (non-recession: 0.407 ($p < 0.10$); recession: -0.561 ($p < 0.10$)). This pattern is also observed at higher levels of statistical significance for innovation followers. Among non-European innovation leaders, we find that the growth of $GBARD$ turns from procycical outside recessions (0.382, $p < 0.10$) to acyclical at the onset of a recession (-0.440, $p > 0.10$). This response pattern is not observed for moderate innovators, where government-financed R&D expenditures are procyclical both during and outside of recessions. The evidence is somewhat weaker for $GBARD$, which turns from procyclicality outside of recession periods to acyclicality in recession periods. This last finding suggests that moderate innovators make stronger budget cuts in public R&D during recessions than they initially planned.

In summary, the analysis in Table 4 highlights some important asymmetries and heterogeneities. First, in recessions, governments deviate from their generally pro-cyclical public R&D spending behavior and on average leave public R&D at the same level despite negative GDP growth. The reason for the observed asymmetric behavior is rooted in a greater need for (Keynesian) stabilizing interventions, including in public R&D, among policy makers 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 to a lesser extent, show more procyclical public R&D spending patterns than innovation leaders and highly innovative non-EU countries do. Third, although we observe acyclicality in recessions on average across all countries, European innovation leaders and innovation followers deviate from this behavior and pursue countercyclical innovation policies during recessions. By increasing public innovation expenditures in periods when private investment lags, these countries' total R&D investment remains closer to that in non-crisis times, effectively increasing their lead on other countries. This innovation gap in public R&D policy in recessions is likely to contribute to a widening gap in productivity and economic growth between the strongest and weakest European innovators over time.

Our results in section 4.2 show procyclicality over the whole business cycle, which is in line with arguments related to the liquidity effect and the voracity effect. To shed further light on the role of liquidity constraints on procyclicality, we investigate to what extent the cyclicality of public R&D is contingent on the country's debt level. Table 5 shows corresponding results on heterogeneities based on debt level. We group countries as having high or low debt, including the four countries with the highest average debt-to-GDP ratio in 1995-2017 in the high-debt group.[25] Models (1) and (3) indicate that, although both groups invest on average procyclically, high-debt countries invest more procyclically in public R&D than low-debt countries do, with an elasticity that is two to three times larger. Models (2) and (4) also show that these differences are driven by non-recession periods, as outside of recessions, high debt-countries' $GBARD$ and $GovFinRD$ are much more procyclical than those of low-debt countries. However, during recessions $GBARD$ and $GovFinRD$ become acyclical, regardless of debt levels. Whereas both groups seem able to stave off large shifts in public R&D funding during recessions, the difference in cyclicalities between the two periods is much stronger for high-debt countries. Thus, these findings indicate that debt levels affect the general cyclicality of public R&D, which is much in line with the liquidity argument for public R&D (Kim 2014), and analog to the financial constraint argument for private R&D spending (Aghion et al. 2010, 2012). However, during recessions the need to support R&D in the economy and to compensate for falling private R&D appears to be stronger than the constraints imposed by debt levels and access to credit.

4.4 Business cycles and the allocation of public R&D

So far, our analysis has focused on how business cycles affect public R&D expenditures. This is important because the degree to which governments can account for shortages in private R&D spending through countercyclical public R&D policies determines to what degree potential innovations are delayed or even lost because of an economic crisis. However, business cycles can have a more nuanced impact on technological progress, not by affecting how much R&D is done, but where it is done. In the next two subsections, we explore this possibility through two additional analyses. In subsection 4.4.1, we split public R&D expenditures by socio-economic objective to see whether business cycles lead to shifts in socio-economic priorities, while subsection 4.4.2 examines whether the share of public R&D expenditures carried out in the business sector (as opposed to the public and higher education sectors) changes over the business cycle.

4.4.1 Allocation of public R&D by socio-economic objective

The MSTI data differentiate seven thematic categories for $GBARD$ (OECD 2016). First, $GBARD$ is broken down into *Defence R&D*, which is all defence R&D excluding civilian R&D financed by defence ministries, and *Civil R&D* which is publicly financed R&D for civil purposes. *Civil R&D* is then further broken down into six categories: economic, health and environment, education and society, space, non-oriented research, and general university funds.[26]

We estimate our benchmark model separately for each category (as a share of $GBARD$). Since we found significant heterogeneity and asymmetry regarding the effect of GDP

[25] See Table 5 for additional details.

[26] See Table 13 in the appendix for definitions of these categories.

Table 5: Effect of business cycles on public R&D expenditures, by national debt level

y_t	$Gr(GovFinRD)_t$		$Gr(GBARD)_t$	
	(1) OLS	(2) OLS	(3) OLS	(4) OLS
$Gr(GDP)_t$ × Low debt	0.364**		0.319*	
	(0.145)		(0.155)	
$Gr(GDP)_t$ × High debt	0.815***		0.922***	
	(0.213)		(0.188)	
$Gr(GDP)_t$ × Low debt × No rec		0.384*		0.508**
		(0.194)		(0.241)
$Gr(GDP)_t$ × Low debt × Rec		0.440		-0.242
		(0.589)		(0.659)
$Gr(GDP)_t$ × High debt × No rec		1.359***		1.319***
		(0.452)		(0.258)
$Gr(GDP)_t$ × High debt × Rec		-0.095		0.125
		(0.363)		(0.297)
$ln(GDP)_{t-1}$	0.002	0.003*	0.002	0.001
	(0.002)	(0.002)	(0.001)	(0.002)
$Surplus_{t-1}$	0.313**	0.319**	0.509***	0.517***
	(0.122)	(0.127)	(0.095)	(0.097)
$Debt_{t-1}$	-0.019	-0.030	-0.005	-0.008
	(0.018)	(0.018)	(0.013)	(0.016)
$Interest_{t-1}$	0.230	0.194	0.285	0.247
	(0.273)	(0.254)	(0.278)	(0.276)
y_{t-1}	0.167*	0.169*	0.107**	0.107**
	(0.094)	(0.094)	(0.043)	(0.042)
N * T	373	373	475	475
R^2	0.197	0.204	0.198	0.207

Notes: This table provides OLS regressions for $Gr(GovFinRD)$ and $Gr(GBARD)$, where we allow the effect of the business cycle, $Gr(GDP)$, to vary by national debt and recession period. Each interacted coefficient represents the coefficient of $Gr(GDP)$ for that subgroup. We define high-debt countries as those with the highest average debt in 1995-2017, and include Japan (211% of GDP), Greece (134%), Italy (130%), and Belgium (120%). The results are not sensitive to the definition of high debt, to including the country with the next highest average debt-to-GDP ratio (Canada, 107%), to omitting Belgium, or to taking a more general approach according to which the upper decile of $Debt_t$ is considered high debt. Rec and No rec indicate recession and non-recession periods, respectively. Standard errors are clustered by country. *** p<0.01, ** p<0.05, * p<0.1. For further notes, see also Table 3.

growth on total $GBARD$, as discussed in section 4.3, we also allow for interaction terms of $Gr(GDP)$ simultaneously with innovation status and recession period. Table 13 in the appendix shows the results. Overall, however, the allocation of $GBARD$ by socio-economic themes is not significantly influenced by the business cycle. Whereas it might be expected that countries assign a higher share of public R&D to R&D that is intended to foster economic development, we do not find evidence to support that hypothesis.[27]

4.4.2 Allocation of public R&D by beneficiary

Beyond the thematic allocation of public R&D, policy makers also decide where publicly financed R&D is performed: in public-sector entities like government research institutes and public universities or in the business sector. Shifting public R&D expenditures to the

[27] We also estimated the model without interaction terms. On average, we did not find a significant relationship between any category of public R&D and $Gr(GDP)$.

private sector by, for instance, expanding budgets for R&D support schemes in response to economic crises could compensate for falling privately financed R&D in the business sector. Therefore, we investigate whether government-financed R&D performed in the business sector as a share of total government-financed R&D evolves pro- or countercyclically along the business cycle by using it as the dependent variable in our benchmark model.

Models (1) to (5) of Table 6 use several estimators to show the cyclicality of the share of government-financed R&D allocated to the business sector (similar to Table 3). Across all models, we derive a rather robust conclusion: The share of government-financed R&D that is allocated to the business sector behaves countercyclically. A one percentage point decrease in the growth rate of GDP relates to a 0.08-0.14 percentage point increase in the share of government-financed R&D in the business sector. As explained in section 4.2, the estimators are based on assumptions that are more or less likely to be given in the data. However, our preferred A-B estimator in Table 3 indicates, in addition to the lack of second-order autocorrelation, no evidence for first-order autocorrelation. This finding suggests that the simple model in first differences should provide consistent estimates (Arellano and Bond 1991). The FD estimates in Table 6 show significant countercylicality of 0.109 percentage points ($p < 0.05$), but the FD estimator does not correct for biases induced by small N dynamic panels. When we use the LSDVC estimator, countercyclicality gets a little smaller at 0.075 percentage points, and becomes statistically insignificant.[28] The table also shows the model when we allow for heterogeneity in terms of countries' innovation status and asymmetric behavior in recession periods vs. non-recession periods. The countercyclicality observed in the previous models seems to be driven primarily by innovation followers that countercyclically shift a larger share of R&D budgets to the business sector during recessions.

Considering the general procyclicality of public R&D spending, this result provides an important nuance: Whereas the level of public R&D expenditures does not increase during crises, some governments do seem to refocus public R&D on the private sector. This mechanism could at least partially offset a decline in private R&D spending, although perhaps this might come at the cost of other research programs. However, this effect is relatively minor in size, operating at fractions of the share of public R&D that is allocated to the public sector.

On the whole, our analysis of the allocation of public R&D by thematic area and recipient shows that the countercyclical spending of leading and following innovators during crises does not coincide with changes in the thematic composition of $GBARD$. But we also find that the share of government-financed R&D that is performed in the business sector is countercyclical for innovation followers during recessions; in other words, innovation followers tend to shift public research to business when private R&D spending decreases during economic crises.

[28] This result holds for the two-sided test. A test of countercyclicality in a one-sided test finds significance at the 10% level ($p = 0.090$).

Table 6: Effect of business cycles on the share of government-financed R&D expenditure allocated to the business sector

	(1) OLS	(2) FE	(3) A-B	(4) FD	(5) LSDVC	(6) LSDVC
$Gr(GDP)_t$	-0.098	-0.078	-0.114**	-0.109**	-0.075	
	(0.064)	(0.066)	(0.053)	(0.052)	(0.056)	
$Gr(GDP)_t$ × L × No rec						0.065
						(0.213)
$Gr(GDP)_t$ × L × Rec						0.219
						(0.347)
$Gr(GDP)_t$ × F × No rec						-0.019
						(0.100)
$Gr(GDP)_t$ × F × Rec						-0.610**
						(0.288)
$Gr(GDP)_t$ × M × No rec						0.036
						(0.127)
$Gr(GDP)_t$ × M × Rec						-0.081
						(0.259)
$Gr(GDP)_t$ × N × No rec						-0.380*
						(0.201)
$Gr(GDP)_t$ × N × Rec						0.033
						(0.484)
$ln(GDP)_{t-1}$	0.002	0.011	-0.066	-0.116	0.022	0.022
	(0.001)	(0.017)	(0.051)	(0.102)	(0.018)	(0.018)
$Surplus_{t-1}$	-0.041	-0.036	-0.078	-0.037	-0.035	-0.039
	(0.048)	(0.053)	(0.118)	(0.042)	(0.063)	(0.063)
$Debt_{t-1}$	-0.005	-0.005	-0.007	0.002	-0.008	-0.009
	(0.004)	(0.011)	(0.026)	(0.032)	(0.012)	(0.011)
$Interest_{t-1}$	0.067	0.140	0.234	0.108	0.140	0.142
	(0.091)	(0.128)	(0.209)	(0.129)	(0.125)	(0.125)
y_{t-1}	0.923***	0.769***	0.413***		0.880***	0.890***
	(0.019)	(0.037)	(0.141)		(0.033)	(0.034)
Constant	-0.010	-0.116		0.002		
	(0.015)	(0.234)		(0.003)		
FE	NO	YES	YES	YES	YES	YES
N * T	351	351	321	329	351	351
R^2	0.883	0.631		0.024		
Hansen Test			19.703			
(p-value)			0.997			
A-B Test						
AR(1)			-1.275			
(p-value)			0.202			
AR(2)			1.101			
(p-value)			0.271			

Notes: This table provides regressions on the effect of business cycles on the government-financed R&D allocated to the business sector as a share of in total government-financed R&D. Each interacted coefficient represents the coefficient of $Gr(GDP)$ for that subgroup. The coefficients of $Gr(GDP)$, $Surplus_{t-1}$, $Debt_{t-1}$, and $Interest_{t-1}$ are scaled up with a factor of 100. Standard errors in columns (1)-(4) are clustered by country. Bootstrapped standard errors for LSDVC are in columns (5)-(6). *** p<0.01, ** p<0.05, * p<0.1. The A-B estimates instrument the endogenous variable $y_{it-1} - y_{it-2}$ with two lagged levels of y (i.e., y_{it-2} and y_{it-3}). All other regressors are assumed to be strictly exogenous. For additional notes, see Tables 3 and 4.

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 procycical 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 28 OECD countries between 1995 and 2017. 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 provides novel insights into three important questions: whether public R&D reacts asymmetrically to GDP growth in recessions compared to non-recession periods, whether governments' R&D responses are contingent on a country's national debt level and capacity for innovation, and whether governments shift their allocations of public R&D over the business cycle in terms of both socio-economic themes and beneficiaries.

Our results reveal a nuanced pattern. On average, public R&D expenditures are procyclical, increasing during economic upturns and decreasing during economic contractions. A one percentage point decrease in GDP growth relates to a drop of 0.35 percent in GBARD, and a drop in government-financed R&D of around 0.44 percent. For growth rates, we find a 0.38 percent increase for GBARD and a 0.42 percent increase for government-financed R&D. The difference between the two suggests that governments tend to plan a less procyclical reaction to business cycle variations than they ultimately implement. Our finding of procyclicality is in line with the liquidity effect and the voracity effect, two theoretical arguments made in the literature, and fits with the idea that economic crises pressure governments to adopt austerity, which usually leads to procyclical government spending (Lane 2003; Alesina et al. 2008). Given the predominantly observed procyclical private R&D expenditures, our finding of procyclicality in public R&D also suggests that, over the whole business cycle, governments, do not compensate for declining (increasing) private R&D spending by increasing (declining) public R&D spending.

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 pro-cyclical public R&D spending behavior during recessions and leave public R&D largely unchanged, despite negative GDP growth and increased pressure to cut back public spending amid falling tax income. We also show that this government reaction in recessions does not depend on countries' financial constraints. During recessions, the need to support R&D in the economy and to compensate for falling private R&D appears to be stronger than the constraints imposed by debt and access to credit. Therefore, this finding for public R&D is in contrast to other findings that financial constraints lead to procyclical private R&D in recessions (Aghion et al. 2010, 2012).

We also document strong national heterogeneities in public R&D responses, depending on the country's innovation performance. Public R&D spending of the strongest European innovators and highly innovative non-European OECD countries is generally acyclical and does not vary with the business cycle. In contrast, European countries with weaker innovation track records behave procyclically, driving our overall finding of procyclicality. We also find that countries that carry high debt act more procyclically, but this difference is driven only by non-recession periods.

These heterogeneous findings also conceal important asymmetries in government responses. In particular, we show that the missing cyclical behaviour across the entire business cycle of European innovation leaders and innovation followers is the result of procyclical public R&D spending in non-recession periods, which turns into a strongly countercyclical behaviour in recessions. This response is much stronger during crises than that of moderate innovators. Moderate innovators' GBARD also changes from procyclicality in non-recession periods to acyclicality in recessions. However, government-financed R&D is procyclical both during and outside of recessions. Comparing the responses of strong and weak innovators during the crises, we thus conclude that the strongest innovators clearly differentiate themselves by means of a countercyclical spending strategy during recessions and thereby contribute to a widening innovation gap.

Finally, we show that, even though GBARD and government-financed R&D change over the business cycle, the way in which public R&D is used is largely stable. In particular, we do not find that governments significantly shift public R&D to domains that are supposedly key to long-term economic growth to compensate in part for a lower volume of public R&D in recessions. However, we also find that governments reallocate budgets by assigning a larger share of public R&D to the business sector when the economy contracts. This result is primarily driven by innovation followers, who compensate for lower overall public R&D spending in recessions by shifting more of it towards the private sector.

Our findings have important implications for R&D policy. Given the strong evidence that private R&D investment behaves procyclically, except for a small group of financially unconstrained firms,[29] the degree to which public policy can compensate for this procyclicality seems key to safeguarding long-term growth prospects in economic crises. The evidence shown here indicates that governments are aware of the importance of public R&D and therefore leave public R&D budgets largely unchanged in recessions despite negative GDP growth. Only countries with a stronger innovation track record even increase public R&D countercyclically during recessions. We do not find that government responses in recessions is primarily a matter of financial constraints, as we do not find differences between countries that carry high vs. low debt: these responses are more a question of countries' innovation capacity and the degree to which they rely on innovation for economic growth.

Our results imply that only few countries compensate falling RD expenditures in the private sector with increases in public RD during economic crises. In the long run, fail-

[29]See section 2 and the references cited therein.

ure to address these discrepancies could contribute to long-term international differences in technology-driven growth. In particular, our results point out differences between the public R&D strategies of innovation leaders and innovation followers on the one hand, and those of moderate innovators on the other hand, that might be at the root of a widening innovation gap: innovation leaders and innovation followers might experience smaller (or no) setbacks in terms of innovation because of business cycles while others do. In that regard, Censolo and Colombo (2019) document substantial heterogeneity in total R&D in Europe, as core European countries tend to invest countercyclically, whereas peripheral countries invest procyclically. To the extent that policy makers consider reducing differences between countries in innovative capacity a priority, they could still increase their resilience to crises by taking on a more countercyclical stance toward public R&D. For example, European policy makers 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.

References

Abbott, A. and P. Jones (2011): "Procyclical government spending: Patterns of pressure and prudence in the OECD," *Economics Letters*, 111, 230–232.

Aghion, P., G.-M. Angeletos, A. Banerjee, and K. Manova (2010): "Volatility and growth: Credit constraints and the composition of investment," *Journal of Monetary Economics*, 57, 246–265.

Aghion, P., P. Askenazy, N. Berman, G. Cette, and L. Eymard (2012): "Credit constraints and the cyclicality of R&D investment: Evidence from France," *Journal of the European Economic Association*, 10, 1001–1024.

Aghion, P. and P. Howitt (1992): "A model of growth through creative destruction," *Econometrica*, 60, 323–351.

Aghion, P. and P. W. Howitt (2009): *The Economics of Growth*, MIT press.

Aghion, P. and G. Saint-Paul (1998): "Virtues of bad times: Interaction between productivity growth and economic fluctuations," *Macroeconomic Dynamics*, 2, 322–344.

Alesina, A., F. R. Campante, and G. Tabellini (2008): "Why is fiscal policy often procyclical?" *Journal of the European Economic Association*, 6, 1006–1036.

Arellano, M. and S. Bond (1991): "Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations," *The Review of Economic Studies*, 58, 277–297.

Arreaza, A., B. E. Sgrensen, and O. Yosha (1999): "Consumption smoothing through fiscal policy in OECD and EU countries," in *Fiscal Institutions and Fiscal Performance*, ed. by J. M. Poterba and J. von Hagen, University of Chicago Press, 59–80.

Barlevy, G. (2007): "On the cyclicality of research and development," *American Economic Review*, 97, 1131–1164.

Bloom, N. (2007): "Uncertainty and the dynamics of R&D," *American Economic Review*, 97, 250–255.

——— (2014): "Fluctuations in uncertainty," *Journal of Economic Perspectives*, 28, 153–76.

Bovha Padilla, S., J. P. Damijan, and J. Konings (2009): "Financial constraints and the cyclicality of R&D investment: Evidence from Slovenia," LICOS Discussion Paper 239/2009.

Bruno, G. S. (2005a): "Approximating the bias of the LSDV estimator for dynamic unbalanced panel data models," *Economics Letters*, 87, 361–366.

——— (2005b): "Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals," *The Stata Journal*, 5, 473–500.

Cao, C., R. P. Suttmeier, and D. F. Simon (2006): "China's 15-year science and technology plan," *Physics Today*, 59, 38.

Censolo, R. and C. Colombo (2019): "R&D intensity of investment across Europe before and after the crisis," *Australian Economic Papers*, 58, 150–167.

Comin, D. and M. Gertler (2006): "Medium-term business cycles," *American Economic Review*, 96, 523–551.

Cornell University, INSEAD, and WIPO (2019): *Global Innovation Index 2019: Creating Healthy Lives — The Future of Medical Innovation*, Cornell University, INSEAD, and the World Intellectual Property Organization: Ithaca, Fontainebleau, and Geneva.

European Commission (2010): "Europe 2020: A strategy for smart, sustainable and inclusive growth," Tech. Rep. COM (2010) 2020, European Commission, Brussels.

——— (2011): "Effect of the economic crisis on R&D investment," in *Innovation Union Competitiveness Report 2011*, ed. by European Commission, 60–72.

Eurostat (2009): "Synthesis of National Quality Reports for 2009 R&D and GBAORD statistics," https://ec.europa.eu/eurostat/cache/metadata/Annexes/rd_esms_an2.pdf (accessed May 25, 2020).

——— (2020): "Government budget appropriations or outlays on R&D (gba) - Reference Metadata in Euro SDMX Metadata Structure (ESMS)," https://ec.europa.eu/eurostat/cache/metadata/en/gba_esms.htm (accessed May 25, 2020).

Fabrizio, K. R. and U. Tsolmon (2014): "An empirical examination of the procyclicality of R&D investment and innovation," *Review of Economics and Statistics*, 96, 662–675.

Fatas, A. (2000): "Do business cycles cast long shadows? Short-run persistence and economic growth," *Journal of Economic Growth*, 5, 147–162.

Francois, P. and H. Lloyd-Ellis (2003): "Animal Spirits through Creative Destruction," *American Economic Review*, 93, 530–550.

——— (2009): "Schumpeterian Business Cycles with Pro-Cyclical R&D," *Review of Economic Dynamics*, 12, 567–591.

Guellec, D. and E. Ioannidis (1997): "Causes of fluctuations in R&D expenditures – A quantitative analysis," *OECD Economic Studies*, 29, 123–138.

Himmelberg, C. P. and B. C. Petersen (1994): "R&D and internal finance: A panel study of small firms in high-tech industries," *The Review of Economics and Statistics*, 76, 38–51.

Hollanders, H., N. Es-Sadki, and M. Kanerva (2016): *European innovation scoreboard 2016*, European Commission.

Hottenrott, H., B. H. Hall, and D. Czarnitzki (2016): "Patents as quality signals? The implications for financing constraints on R&D," *Economics of Innovation and New Technology*, 25, 197–217.

Hud, M. and K. Hussinger (2015): "The impact of R&D subsidies during the crisis," *Research Policy*, 44, 1844–1855.

Izsak, K., P. Markianidou, R. Lukach, and A. Wastyn (2013): "The impact of the crisis on research and innovation policies," *Study for the European Commission DG Research by Technopolis Group Belgium and Idea Consult*.

Kim, S. Y. (2014): "Government R&D funding in economic downturns: Testing the varieties of capitalism conjecture," *Science and Public Policy*, 41, 107–118.

Lane, P. R. (2003): "The cyclical behaviour of fiscal policy: Evidence from the OECD," *Journal of Public Economics*, 87, 2661–2675.

López-García, P., J. M. Montero, and E. Moral-Benito (2013): "Business cycles and investment in productivity-enhancing activities: Evidence from Spanish firms," *Industry and Innovation*, 20, 611–636.

Makkonen, T. (2013): "Government science and technology budgets in times of crisis," *Research Policy*, 42, 817–822.

Mohnen, P. and B. H. Hall (2013): "Innovation and productivity: An update," *Eurasian Business Review*, 3, 47–65.

OECD (2009): *Policy Responses to the Economic Crisis: Investing in Innovation for Long-Term Growth*, OECD Paris.

——— (2012): "Innovation in the crisis and beyond," in *Science, Technology and Industry Outlook 2012*, ed. by OECD, Paris, 21–57.

——— (2015): *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development. The Measurement of Scientific, Technological and Innovation Activities*, Paris: OECD Publishing.

——— (2016): "Main science and Technology Indicators," Tech. rep., Paris.

——— (2019): "Main science and technology indicators 2018/2," Tech. rep., Paris.

——— (2020): "Main science and technology indicators 2019/2," Tech. rep., Paris.

Ouyang, M. (2011): "On the cyclicality of R&D," *The Review of Economics and Statistics*, 93, 542–553.

Paunov, C. (2012): "The global crisis and firms' investments in innovation," *Research Policy*, 41, 24–35.

Rafferty, M. and M. Funk (2004): "Demand shocks and firm-financed R&D expenditures," *Applied Economics*, 36, 1529–1536.

——— (2008): "Asymmetric effects of the business cycle on firm-financed R&D," *Economics of Innovation and New Technology*, 17, 497–510.

Rafferty, M. C. (2003): "Do business cycles influence long-run growth? The effect of aggregate demand on firm-financed R&D expenditures," *Eastern Economic Journal*, 29, 607–618.

Raudla, R. (2010): *Constitution, Public Finance, and Transition: Theoretical Developments in Constitutional Public Finance and the Case of Estonia*, vol. 4, Peter Lang.

Romer, D. (1993): "The new keynesian synthesis," *Journal of Economic Perspectives*, 7, 5–22.

Saint-Paul, G. (1993): "Productivity growth and the structure of the business cycle," *European Economic Review*, 37, 861–883.

Schleifer, A. (1986): "Implementation cycles," *Journal of Political Economy*, 94, 1163–1190.

Schmookler, J. (1966): Harvard University Press.

Shleifer, A. (1986): "Implementation cycles," *Journal of Political Economy*, 94, 1163–1190.

State Council of the People's Republic of China (2015): "'Made in China 2025' plan issued," http://english.www.gov.cn/policies/latest_releases/2015/05/19/content_281475110703534.htm.

Talvi, E. and C. A. Végh (2005): "Tax base variability and procyclical fiscal policy in developing countries," *Journal of Development Economics*, 78, 156–190.

Tornell, A. and P. R. Lane (1999): "The voracity effect," *American Economic Review*, 89, 22–46.

Veugelers, R. (2014): "Undercutting the Future? European research spending in times of fiscal consolidation," Bruegel Working Paper 2014/06, Brussels.

White House (2015): "A Strategy for American Innovation," Washington, DC.

Woo, J. (2009): "Why do more polarized countries run more procyclical fiscal policy?" *The Review of Economics and Statistics*, 91, 850–870.

Wälde, K. and U. Woitek (2004): "R&D expenditure in G7 countries and the implications for endogenous fluctuations and growth," *Economics Letters*, 82, 91–97.

Appendix

Figures

Figure 3: Mean public R&D growth over time

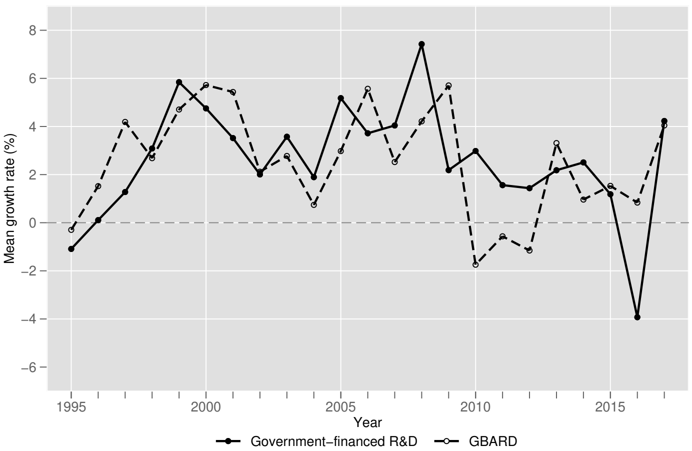


Figure 4: Mean public R&D expenditures over time as % of GDP

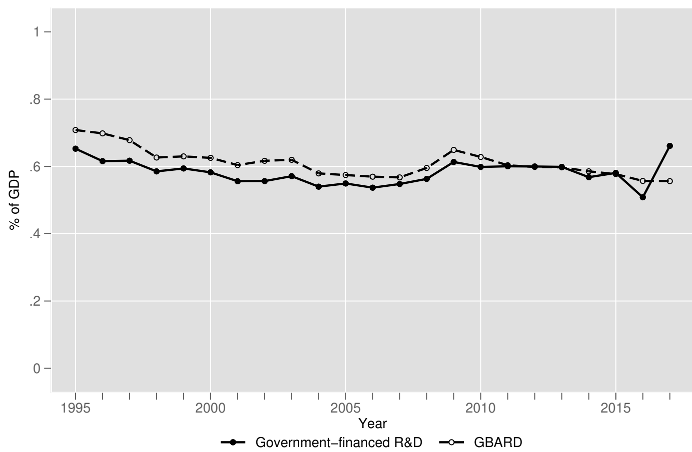
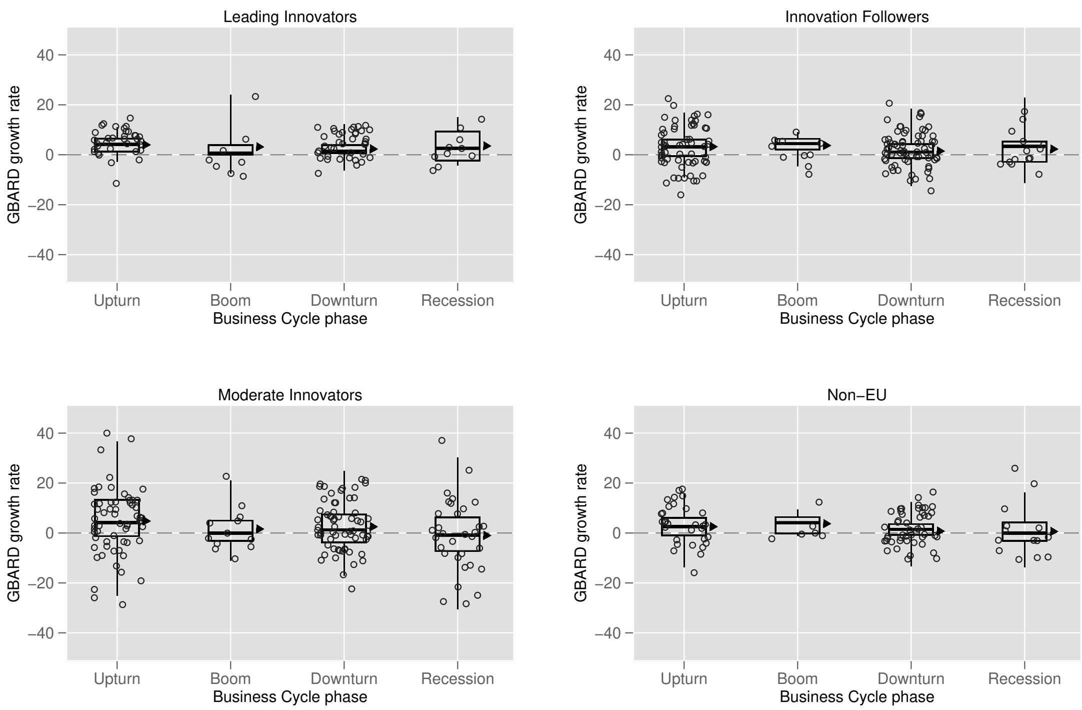


Figure 5: Distribution of GBARD over the business cycle



Notes: The graph shows the growth rate of $GBARD$, across country groups and business cycle phases. The horizontal lines indicate the first quartile, median, and third quartile of the distribution within country group and business cycle phase. The whiskers indicate the 1st and 99th percentiles, and the triangle shows the mean growth rate.

Tables

Table 7: Included Countries

Country	Freq	Status	Years First	Years Last	Business Cycle Years Recess	Up	Boom	Down
Australia	23	N	1995	2017	2	8	2	11
Austria	23	F	1995	2017	2	9	1	11
Belgium	23	F	1995	2017	1	9	3	10
Canada	22	N	1995	2016	3	6	2	11
Czech Republic	17	M	2001	2017	2	6	0	9
Denmark	23	L	1995	2017	3	10	2	8
Finland	23	L	1995	2017	4	7	3	9
France	23	F	1995	2017	3	7	1	12
Germany	23	L	1995	2017	1	9	2	11
Greece	20	M	1998	2017	8	7	1	4
Hungary	13	M	2005	2017	3	6	0	4
Ireland	20	F	1998	2017	2	8	2	8
Israel	17	N	2001	2017	5	5	1	6
Italy	20	M	1995	2017	5	6	2	7
Japan	13	N	2005	2017	2	4	0	7
Latvia	17	M	2001	2017	3	6	2	6
Lithuania	14	M	2004	2017	2	4	2	6
Luxembourg	3	F	2015	2017	0	1	0	2
Netherlands	23	F	1995	2017	2	10	0	11
Poland	15	M	2001	2017	0	7	0	8
Portugal	23	M	1995	2017	4	10	1	8
Slovakia	17	M	2001	2017	1	5	2	9
Slovenia	15	F	2003	2017	2	6	1	6
Spain	23	M	1995	2017	4	9	2	8
Sweden	22	L	1995	2017	2	9	1	10
Switzerland	9	N	2000	2015	0	5	1	3
United Kingdom	23	F	1995	2017	2	10	2	9
United States	23	N	1995	2017	2	7	1	13

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 European Innovation Scoreboard (Status; L = Innovation Leader, F = Innovation Follower, M: Moderate Innovator, N: Non-European Country), (3) the first and last observed year, and (4) the number of observations per business cycle stage (Business Cycle Years; Recess = Recession, Up = Upswing, Down = Downturn).

Table 8: Number of observations by innovation status and business cycle stage

	Recess	Up	Boom	Down	Total
Leading Innovators	10	35	8	38	91
Innovation Followers	14	60	10	69	153
Moderate Innovators	32	66	12	69	179
Non-EU	14	35	7	51	107
Total	70	196	37	227	530

Notes: The table shows the number of observations in our sample across innovation status and country-specific business cycle stage. Recession equals 1 if the country-specific annual GDP growth is negative. An upturn is a year in which the GDP growth rate is positive and increasing, while specifically a year in which the GDP growth is positive and increasing but subsequently decreasing is marked as a boom period. A downturn characterizes years with positive but decreasing GDP growth.

Table 9: Correlation Matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. $ln(GovFinRD)$	1.000								
2. $ln(GBARD)$	0.994***	1.000							
3. $ln(GDP)$	0.977***	0.975***	1.000						
4. $Gr(GovFinRD)$	-0.015	-0.028	-0.034	1.000					
5. $Gr(GBARD)$	-0.052	-0.027	-0.046	0.523***	1.000				
6. $Gr(GDP)$	-0.041	-0.042	-0.033	0.219***	0.177***	1.000			
7. $Surplus$	-0.077	-0.073	-0.128**	0.133**	0.175***	0.288***	1.000		
8. $Debt$	0.426***	0.412***	0.450***	-0.137**	-0.104*	-0.114**	-0.338***	1.000	
9. $Interest$	-0.219***	-0.184***	-0.156***	-0.090	-0.062	-0.220***	-0.274***	-0.087*	1.000

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

Table 10: Effect of business cycles on public R&D: joint sample

	Level							Growth		
y_t	$ln(GovFinRD)_t$					$ln(GBARD)_t$		$Gr(GovFinRD)_t$		$Gr(GBARD)_t$
	(1) OLS	(2) FE	(3) FD	(4) A-B	(5) LSDVC	(6) A-B	(7) LSDVC	(8) OLS	(9) OLS	(10) OLS
$Gr(GDP)_t$	-0.161	0.279	0.402**	0.180	0.436***	0.364	0.344**	0.452***	0.395***	0.332*
	(0.689)	(0.349)	(0.180)	(0.172)	(0.145)	(0.237)	(0.146)	(0.155)	(0.138)	(0.161)
$ln(GDP)_{t-1}$	1.117***	1.414***	0.663**	0.571***	0.164***	0.655**	0.142**	0.002	0.002	0.002
	(0.046)	(0.121)	(0.272)	(0.190)	(0.058)	(0.286)	(0.069)	(0.003)	(0.002)	(0.002)
$Surplus_{t-1}$	0.923	-0.496	-0.154	-0.216	0.341**	-0.159	0.567***	0.404**	0.351**	0.562***
	(1.160)	(0.446)	(0.255)	(0.345)	(0.135)	(0.457)	(0.171)	(0.151)	(0.125)	(0.117)
$Debt_{t-1}$	-0.036	-0.053	-0.122	-0.101	-0.069***	-0.125*	-0.064**	-0.016	-0.010	0.000
	(0.115)	(0.103)	(0.102)	(0.080)	(0.026)	(0.065)	(0.030)	(0.016)	(0.014)	(0.012)
$Interest_{t-1}$	-2.154*	0.829	-0.320	0.169	0.280	0.325	0.122	0.155	0.229	0.315
	(1.153)	(0.558)	(0.379)	(0.600)	(0.312)	(0.818)	(0.353)	(0.353)	(0.285)	(0.373)
y_{it-1}				0.612***	0.928***	0.394	0.906***		0.184*	0.155***
				(0.176)	(0.033)	(0.244)	(0.034)		(0.093)	(0.037)
Constant	-6.586***	-10.709***	0.012					0.013	0.002	-0.008
	(0.689)	(1.600)	(0.009)					(0.041)	(0.037)	(0.036)
FE	NO	YES	YES	YES	YES	YES	YES	NO	NO	NO
N * T	375	375	351	346	374	345	371	375	368	367
R^2	0.962	0.715	0.078					0.084	0.108	0.120
Hansen Test				19.051		19.019				
(p-value)				(0.998)		(0.998)				
A-B Test										
AR(1)				-1.816		-0.988				
(p-value)				(0.069)		(0.323)				
AR(2)				0.564		-0.908				
(p-value)				(0.573)		(0.364)				

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. *** p<0.01, ** p<0.05, * p<0.1. Coefficient of $Gr(GDP)$, $Surplus_{t-1}$, $Debt_{t-1}$, and $Interest_{t-1}$ are scaled up with a factor of 100.

Table 11: Arellano-Bond GMM estimates using alternative sets of instruments

Panel A: ln(GovFinRD)$_t$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$Gr(GDP)_t$	0.216	0.363*	0.255	0.262	0.376*	0.290	0.345
	(0.165)	(0.199)	(0.187)	(0.205)	(0.200)	(0.197)	(0.215)
y_{t-1}	0.611**	0.629***	0.458*	0.560**	0.611***	0.601**	0.514**
	(0.245)	(0.219)	(0.246)	(0.246)	(0.218)	(0.234)	(0.246)
N * T	351	351	351	351	351	351	351
N	24	24	24	24	24	24	24
FE	YES	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES	YES
Number of Instruments	46	276	66	87	257	66	86
$Gr(GDP)_t$ Instruments							
First lag	-	1	1	1	2	2	2
Last lag	-	All	1	2	All	2	3
Hansen Test	19.431	19.637	20.956	20.078	19.891	19.770	20.199
(p-value)	(0.997)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)
A-B Test							
AR(1)	-1.662	-1.715	-1.245	-1.476	-1.689	-1.665	-1.378
(p-value)	(0.096)	(0.086)	(0.213)	(0.140)	(0.091)	(0.096)	(0.168)
AR(2)	0.888	0.760	0.989	0.817	0.758	0.852	0.848
(p-value)	(0.375)	(0.447)	(0.323)	(0.414)	(0.449)	(0.394)	(0.396)

Panel B: ln(GBARD)$_t$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$Gr(GDP)_t$	0.326*	0.319	0.301	0.338	0.309	0.357	0.362
	(0.178)	(0.243)	(0.201)	(0.217)	(0.244)	(0.246)	(0.222)
y_{t-1}	0.552**	0.633***	0.497*	0.490**	0.637***	0.421*	0.547**
	(0.261)	(0.195)	(0.273)	(0.240)	(0.194)	(0.240)	(0.234)
N * T	448	448	448	448	448	448	448
N	27	27	27	27	27	27	27
FE	YES	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES	YES
Number of Instruments	46	297	66	87	276	66	86
$Gr(GDP)_t$ Instruments							
First lag	-	1	1	1	2	2	2
Last lag	-	All	1	2	All	2	3
Hansen Test	22.133	21.827	22.857	23.016	21.818	23.359	22.387
(p-value)	(0.990)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)
A-B Test							
AR(1)	-1.631	-2.336	-1.402	-1.552	-2.357	-1.272	-1.809
(p-value)	(0.103)	(0.019)	(0.161)	(0.121)	(0.018)	(0.203)	(0.070)
AR(2)	-1.060	-1.073	-1.042	-1.068	-1.074	-1.006	-1.052
(p-value)	(0.289)	(0.283)	(0.298)	(0.286)	(0.283)	(0.314)	(0.293)

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. Columns (2) to (4) assume $Gr(GDP)_t$ to be predetermined while columns (5) to (7) allow it to be endogenous. While columns (2) and (5) use all available instruments available under the respective assumption, the other estimates limit the number of lags included as instrument as indicated by "last lag". standard errors are clustered by country. *** p<0.01, ** p<0.05, * p<0.1. Coefficients of $Gr(GDP)$ scaled up with a factor of 100. Regressions also include $Surplus_{t-1}$, $Debt_{t-1}$ and $Interest_{t-1}$.

Table 12: *GBARD* by socio-economic objective: summary statistics

Panel A: Full Sample				
	N*T	Mean	Min	Max
Defence	397	6.864	0.000	54.131
Civil	397	93.136	45.869	100.000
Econ	397	21.924	5.213	45.813
Health & Environment	397	13.074	2.013	33.806
Educ & Social	397	4.568	0.278	22.129
Space	397	3.405	0.000	14.468
Non-oriented	397	18.398	1.071	61.520
Uni	397	31.767	0.000	72.184
Panel B: By Country Innovation Status				
	Recess	Up	Boom	Down
Defence	4.753	6.199	7.039	8.092
Civil	95.247	93.801	92.961	91.908
Econ	21.367	22.101	22.204	21.909
Health & Environment	12.865	13.025	13.718	13.099
Educ & Social	5.997	4.619	5.097	4.003
Space	3.199	3.131	4.071	3.624
Non-oriented	17.256	18.786	18.434	18.414
Uni	34.563	32.139	29.437	30.858
N * T	54	150	22	171

Notes: This table shows the average share of *GBARD* that is assigned to each socio-economic objective. Panel A shows the full sample. Panel B shows mean spending by country innovation status.

Table 13: Effect of business cycles on $GBARD$ by socio-economic objective

y_t	(1) Civil	(2) Econ	(3) Health & Envir	(4) Educ & Social	(5) Space	(6) Non-orient	(7) Uni
$Gr(GDP)_t$ × L × No rec	0.146*	0.415	-0.044	-0.123	0.005	-0.027	0.082
	(0.081)	(0.535)	(0.401)	(0.083)	(0.026)	(0.396)	(0.325)
$Gr(GDP)_t$ × L × Rec	-0.161	0.091	0.087	0.351	-0.106	1.088	0.308
	(0.372)	(1.323)	(0.313)	(0.282)	(0.112)	(2.093)	(0.930)
$Gr(GDP)_t$ × F × No rec	0.023	0.113	-0.024	-0.054***	0.011	0.134	-0.021
	(0.032)	(0.201)	(0.035)	(0.019)	(0.043)	(0.126)	(0.265)
$Gr(GDP)_t$ × F × Rec	-0.180	-0.906	0.063	0.039	-0.050	-0.641	-0.163
	(0.428)	(2.241)	(0.091)	(0.142)	(0.064)	(1.103)	(2.065)
$Gr(GDP)_t$ × M × No rec	0.064	0.228	0.000	-0.053	-0.020	-0.275	-0.010
	(0.109)	(0.322)	(0.228)	(0.089)	(0.016)	(0.516)	(0.204)
$Gr(GDP)_t$ × M × Rec	0.036	-0.433	0.190	0.247	-0.052	-0.060	0.093
	(0.325)	(0.601)	(0.228)	(0.250)	(0.043)	(0.509)	(0.194)
$Gr(GDP)_t$ × N × No rec	0.374*	0.166	-0.016	-0.187	-0.055	0.267	-0.204
	(0.207)	(0.629)	(0.251)	(0.417)	(0.042)	(0.802)	(0.482)
$Gr(GDP)_t$ × N × Rec	-2.401	-0.737	-0.672	0.797	0.097	-1.717	-0.758
	(1.528)	(2.864)	(1.178)	(2.128)	(0.222)	(4.590)	(3.122)
$ln(GDP)_{t-1}$	0.025	-0.010	0.001	0.004	-0.014**	0.007	-0.045
	(0.020)	(0.074)	(0.048)	(0.018)	(0.006)	(0.035)	(0.053)
$Surplus_{t-1}$	-0.040	0.068	0.010	0.083***	-0.014	-0.060	-0.080
	(0.033)	(0.095)	(0.040)	(0.030)	(0.021)	(0.122)	(0.117)
$Debt_{t-1}$	0.003	0.014	0.002	-0.006	0.002	-0.030	0.016
	(0.012)	(0.030)	(0.022)	(0.013)	(0.003)	(0.032)	(0.023)
$Interest_{t-1}$	0.062	-0.025	-0.189	0.029	-0.049**	-0.036	-0.240
	(0.063)	(0.299)	(0.200)	(0.079)	(0.020)	(0.291)	(0.261)
y_{t-1}	0.576***	0.614**	0.190	0.579***	0.687***	0.829***	0.425*
	(0.212)	(0.259)	(0.198)	(0.195)	(0.121)	(0.208)	(0.218)
N * T	425	425	425	425	425	425	425
Hansen Test	14.264	19.177	15.928	15.475	11.761	15.477	18.564
(p-value)	0.817	0.510	0.721	0.749	0.924	0.749	0.550
A-B Test							
AR(1)	-1.733	-1.897	-1.284	-2.233	-2.247	-2.278	-1.600
(p-value)	0.083	0.058	0.199	0.026	0.025	0.023	0.110
AR(2)	0.261	-0.889	1.272	0.994	1.506	-1.205	-0.070
(p-value)	0.794	0.374	0.203	0.320	0.132	0.228	0.944

Notes: This table provides A-B estimations for $GBARD$ by socio-economic objective. The dependent variable is the share of $GBARD$ assigned to the objective. $GBARD$ categories follow MSTI definitions (OECD 2016, documentation, p. 3): Civil: Total share of GBARD allocated to non-defence purposes. Econ: R&D programs for transport, telecommunication, infrastructure, energy, industrial production and technology, agriculture. Health & envir: R&D programs for exploration and exploitation of the earth, environment, and health. Educ & social: R&D programs for education, culture, recreation, religion, mass media, and for political and social systems, structure and processes. Space: civil space R&D programs. Non-orient: Research programs for the general advancement of knowledge. Uni: estimated R&D content of block grants from government to higher education sector. See Table 12 in the appendix for summary statistics. standard errors are clustered by country. *** p<0.01, ** p<0.05, * p<0.1. The A-B estimates instrument the endogenous variable $y_{it-1} - y_{it-2}$ with two lagged levels of y, i.e. y_{it-2} and y_{it-3}. All other regressors are assumed to be strictly exogenous. For further notes, see also Tables 3 and 4.

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