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Fiscal Decentralization and Public R&D Policy: A Country Panel Analysis

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Abstract

This paper presents a first analysis of the potential link between the level of fiscal decentralization of a country and its public investment in innovation. We present a theoretical model where a 'benevolent government' invests in R&D aiming at maximizing net income, and R&D results are subject to interregional knowledge spillovers. The model predicts that decentralization leads to a lower level of public spending on innovation, and to a lower share of basic research in the government R&D budget. These hypotheses are empirically tested using country aggregate data. The results provide empirical support to the mentioned hypotheses, as we find evidence that higher levels of both expenditure and revenue decentralization are associated with a lower intensity of basic research in public R&D and with a lower level of R&D spending. The strength of the evidence, however, is weakened by the small sample size and shortcomings of the indicators used in the analysis.

Keywords: applied research; basic research; fiscal decentralization; innovation policy; knowledge spillovers

JEL classification: H23, H32, O38

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Introduction

As many countries continue to deepen their decentralization policies (OECD 2016), science, technology and innovation (ST&I) remain central in government strategies to promote growth and overcome societal challenges, especially in the aftermath of the 2008–09 crisis (OECD 2014). In this paper, we examine how these two policy trends interact, and, more specifically, whether there is a significant association between fiscal decentralization and public spending on research and development (R&D).

The fiscal federalism literature (briefly reviewed in the following section) has presented evidence of how the level of decentralization (measured both on the revenue and expenditure sides) affects, among other things, government spending, the assignment of functions, the composition of budgets and the delivery of public policies. The main factors and economic forces that explain such effects are distinct preferences and circumstances among subnational governments (Oates 1999), interjurisdictional spillovers (Hulten and Schwab 1997), factor mobility (Brennan and Buchanan 1980) and state competition (Zodrow and Mieszkowski 1986). The impacts of fiscal decentralization on economic growth and a long list of other government objectives have been recently review by Martinez-Vazquez, Lago-Peñas, and Sacchi (2017). However, up to this point, to the best of our knowledge there has been no research on the impact on ST&I policy and how distinct levels of decentralization can change government incentives to foster innovation.

Similarly, the findings and lessons from the decentralization literature have not been carefully considered in the field of economics of innovation, whether to explain or to provide recommendations for policy design and for the assignment of roles and functions to different levels of government. Yet, there is a strong case to suspect that fiscal decentralization should

affect public spending on R&D, mostly because of the presence of significant knowledge spillovers. After all, Oates' (1972) "fiscal decentralization theorem," which is considered the bedrock of modern fiscal federalism theory, explicitly assumed away the presence of spillovers. Also, as discussed in the next section, different empirical analyses have provided evidence that a substantial part of R&D results is not internalized by the institution developing a new technology and that such externalities spread unevenly throughout different regions, with neighboring agents being in a better position to benefit from new knowledge flows (Peri 2005).

Considering this gap in the literature, this paper aims to present a first analysis and evidence on the link between fiscal decentralization and public spending on R&D. At first, we identify opposing forces that may affect this relationship. On one side, decentralized governance may lead to underprovision of public services characterized by large externalities that are not bounded to the subnational authority jurisdiction (Oates 2008a)—such as in the case of ST&I. On the other side, fiscal competition may generate incentives for subnational governments to increase innovation spending to attract new capital investment (Keen and Marchand 1997). The analysis becomes more complicated once we abandon a uniform view of R&D and distinguish between basic and applied research, with different levels of spillovers and potential to attract investment.[1]

Two main questions are addressed herein: (a) whether the level of fiscal decentralization is a significant explanatory variable of the share of R&D in the government budget, once we control for other relevant country features, and (b) whether decentralization is also associated

[1] Throughout this paper, we use the standard definitions of innovation related concepts presented in the OECD Frascati Manual: Both basic and applied research refer to an original investigation, but the first does not aim at any particular use, while the second is directed at a practical purpose or application; development, on the other hand, is based on a previous existing set of knowledge and has the objective of creating new products or processes, or improving existing ones (OECD 2015).

with the balance between basic research and applied research in the public R&D bundle. To help answer these questions, we first propose a theoretical model explaining the main economic forces that shape the government decision, and then we test its results through an empirical analysis using country panel aggregate data on government expenditures.

The remainder of the paper is structured as follows. In the next section, we discuss the intersection of the economic literatures on fiscal decentralization and knowledge spillovers arising from R&D investments. We then summarize the theoretical model (presented in detail in Appendix A) and derive the propositions to be tested empirically. We follow by describing the data, performing the empirical analysis and discussing the results, along with potential policy implications. The final section concludes and suggests further research agenda on this subject.

Review of the Relevant Literature

The economic debates on fiscal decentralization and on R&D knowledge spillovers constitute the theoretical basis of both the model and the empirical analysis presented later in the paper. Here we review the main relevant arguments and evidence presented by the previous literature on these topics.

Fiscal Decentralization, Interregional Spillovers and the Composition of Public Expenditures

The "traditional branch" of the fiscal federalism theory (Oates 2008a) gives clear guidelines for the division of functions between different levels of government. Following the decentralization theorem (Oates 1972, 1999), local public goods should be more efficiently provided if decentralized to local governments, while global public goods and broad policies such as macroeconomic stability must be carried out at the national level. The original theorem is based on the strong assumption that consumption of these goods is geographically defined. That

means it only accepts the existence of "pure local" (consumption limited to a particular region or area) or global (that benefits all regions) goods (Kappeler and Välilä 2008).

This requirement was relaxed by later studies, allowing for a third type of public goods, which, despite of being consumed locally, generate interregional spillovers that influence the production or welfare of people residing elsewhere (Besley and Coate 2003; Feidler and Staal 2012; Hulten and Schwab 1997; Oates 2008a, b; Ponce-Rodriguez et al. 2018). These externalities reduce the incentives of local governments to efficiently invest in these goods, as part of the benefits arising from them is not internalized within the producing jurisdiction. As a result, this leads to the inefficient underprovision of public goods with externalities in a decentralized policy setup.

The problem of interregional spillovers gains in complexity when factor mobility is recognized. A long strand of the previous literature has argued that households or capital can move to preferred locations to take advantage of lower taxes or higher levels of benefits from public goods or infrastructure (Tiebout 1956). Once mobility is present, one effect is that fiscal decentralization will tend to limit taxing power and government size because local governments have to compete for constituents and resources that are mobile, as in the 'Leviathan hypothesis' (Brennan and Buchanan 1980). Also with mobility, the erosion of the tax base can also lead to an overall reduction of public services provision through a 'race to the bottom' by competing jurisdictions (Zodrow and Mieszkowski 1986), along with the erosion of the welfare state and public infrastructure (Sinn 2003), and also possibly with a reduction of gains arising from economies of scale (Hulten and Schwab 1997).

A separate branch of the fiscal federalism literature has analyzed how decentralization impacts the functioning of the government, both in terms of its political institutions and delivery

of public policies (Martinez-Vazquez, Lago-Peñas and Sacchi 2017). A part of these studies has focused on the composition of government budgets, although this is still a relatively new and underexplored topic (Jia, Guo and Zhang 2014). In theoretical terms, it is also possible that subnational government competition could lead to a 'race to the top.' In the model proposed by Keen and Marchand (1997), regions compete to attract investment, and as a result they overinvest in public input to business (such as infrastructure), at the cost of direct consumption benefits to residents. Subnational governments may also compete to attract mobile households by altering their budget composition, such as raising their expenditure in education (Busemeyer 2007).

Most of the literature on fiscal decentralization and composition of the public budget is comprised of empirically focused studies (for literature reviews, see Martinez-Vazquez, Lago-Peñas and Sacchi 2017; Arze del Granado, Martinez-Vazquez and McNab 2016). The majority of them converge to the conclusion that higher decentralization levels lead to more public productive investment. There is evidence of this result for physical capital, infrastructure and housing (Jia, Guo and Zhang 2014; Kappeler and Välilä 2008; Sacchi and Salotti 2016), and for education, health or human capital (Arze del Granado, Martinez-Vazquez and McNab 2016; Ashworth, Galli and Padovano 2009; Busemeyer 2007; Faguet 2004; Martinez-Vazquez, Lago-Peñas and Sacchi 2017; Kappeler and Välilä 2008; Sacchi and Salotti 2016).

However, up to this point, this literature has largely neglected the analysis of public expenditure in ST&I. Only one of the studies in our literature review considered this spending category in the empirical analysis (Grisorio and Prota 2015), but even in this case, the authors did not include it in their econometric exercise.

R&D and Knowledge Spillovers

The study of innovation policies has received great attention from economists of different schools of thought in the last several decades (Edler and Fagerberg 2017). In theoretical terms, there are sound grounds for public intervention in the field of ST&I, mostly because market failures lead to inefficient underinvestment in R&D by private agents, thus requiring additional public resources to supplement it (Arrow 1962; Köhler, Laredo and Rammer 2012).

Among the failures identified by the literature, the incomplete appropriation of R&D results is considered the most important economic rationale for public innovation policies (Köhler, Laredo and Rammer 2012). Positive externalities or knowledge spillovers are an intrinsic feature of innovation, because of the non-rival and non-excludable nature of knowledge, and also because of very small transmission costs (Arrow 1962). The non-appropriated knowledge can be used by different firms and individuals for production and future research, and as the R&D investing firm does not profit from or appropriate such spillovers, it does not consider them in its spending decisions, leading to suboptimal investment levels. This justifies efficiency-enhancing government action to increase overall R&D spending through public subsidies or other incentives to promote private innovation investment.

As knowledge spillovers obtained a prominent role in innovation and economic growth analysis, a substantial empirical literature has attempted to quantify them (for a review, see Hall, Mairesse and Mohnen 2010). Most studies did find evidence of spillovers arising from R&D (Wieser 2005), and estimates suggest that they actually represent the bulk of innovation outcomes, reaching up to twice the value of internalized results or more (Bernstein and Nadiri 1989; Bloom, Schankerman and Van Reenen 2013).

The impact of spillovers, however, is not even across firms, and geographical distance plays a major role in their dispersal, at least for some time. These externalities are considered spatially localized (Anselin, Varga and Acs 1997; Breschi and Lissoni 2001), as firms located in the same region or country where the technology is developed tend to benefit more from it. Using patent data from European regions until the 1990s, Bottazzi and Peri (2003) concluded that R&D spillovers may be limited to a 300 kilometers range from the region of origin; Peri (2005) estimated that no more than 20 percent of created knowledge leaves such region of origin, while less than 9 percent leaves the country. There is also evidence that firms located close to academic centers are more likely to apply their research findings first (Mansfield and Lee 1996). The main explanations presented for this geographic concentration are the tacit nature of knowledge, geographic barriers to knowledge flows, linguistic factors and the agglomeration of production (Audretsch and Feldman 1996, Maurseth and Verspagen 2002).

A part of such externalities flows to other areas, positively affecting research and productivity at the interregional (Anselin, Varga and Acs 1997; Bottazzi and Peri 2003; Kang, Dall'Erba and Peng 2017) and international levels (Malerba, Mancusi; and Montobbio 2013). The channels of transmission of such knowledge can be direct, i.e., the acquisition of publicly-available information, or indirect, through the mobility of researchers, trade or productivity improvements caused by foreign direct investment (Gersbach 2009; Schetter 2014).

The magnitude and geographic dispersal of knowledge spillovers can be influenced by different factors, such as the nature of innovative R&D. The level of spillovers is an important distinction between basic and applied research. In his seminal article, Nelson (1959) argued that while basic research is the major source of scientific breakthroughs and significant technology developments, it presents ‘substantial external economies’, as its results can be applied in

different fields, and in many cases their value cannot be captured through patents, as they do not constitute practical solutions to existing problems. Basic research often generates larger and more pervasive knowledge externalities that propagate and can be used to improve productivity or to foster innovation across different economic sectors (Denti 2009). Empirical analyses have confirmed that larger spillovers arise from basic research (Salter and Martin 2001), and Griliches (1985) and Lichtenberg and Siegel (1991) have also found a "premium" for basic research, meaning that it is more important for productivity increase.

Moreover, there are arguments to suggest that basic research generates more knowledge spillovers that spread geographically and benefit other regions or countries. In a two-country model, Gersbach and Schneider (2015) concluded that basic research conducted abroad partially substitutes local investment in this activity to foster private innovation, while applied research generates a monopoly to the innovator with no spillovers (for the duration of the patent). A few empirical studies investigated this topic, presenting evidence that support this argument. Analyzing a group of OECD countries, Funk (2002) found that basic research generates much larger international spillovers; according to Anselin, Varga and Acs (1997), R&D at U.S. universities (more directed to basic research) influences innovative activity outside the respective metropolitan statistical area, while the effects of private R&D are contained within such range. Crespi and Geuna (2008) found that, due to the high level of spillovers across OECD countries, basic science should be understood as 'an international enterprise'. Empirical research on university-firm collaboration also suggests that knowledge transfer for basic research is less dependent upon geographical proximity than for applied R&D (Mansfield 1995; Gittelman 2007).

The literature on knowledge spillovers discussed in this section supports the notion that innovation presents typical features of public goods, i.e., non-rivalry and non-excludability (Arrow 1962), and it is treated as such in different studies (Malerba, Mancusi and Montobbio 2013; Verspagen and De Loo 1999). Moreover, its positive externalities are affected by spatial or geographical distance, so that innovation can be considered a case of local public good with interjurisdictional spillovers (Gersbach 2009; Gersbach and Schneider 2015). The fiscal decentralization literature discussed previously suggests that, in these cases, there are grounds to suspect that the provision of such public goods might be influenced by the level of decentralization of government activities in a country. The direction and magnitude of such effect, however, are not clear, and this is a topic that has not been explored by the economic literature so far. The theoretical model (summarized in the next section) and the empirical analysis that follows are a first attempt to fill this gap.

Linking Fiscal Decentralization and Public R&D: Theoretical Propositions

Considering the concepts and arguments discussed in the previous section, we present a simple model in Appendix A to explain how fiscal decentralization can affect the share and composition of government expenditures in R&D, considering the broad categories of basic and applied research. Our objective is to model the economic forces that shape the decision of a 'benevolent government' that aims to maximize net income in the country or in the respective region in the short run (Besley and Coate 2003; Dhillon, Wooders and Zissimos 2007; Zodrow and Mieszkowski 1986).

The model assumes a closed economy with a large number of symmetric regions and one firm located at each region. Firms compete to attract capital, and they also have to pay taxes that

are levied on each unit of capital invested in the respective period.[2] Firms' output depends on the capital they attract to the region and on their production technology level. The state of technology evolves according to (a) the investment made by the government in R&D within the region, (b) the composition of the R&D investment bundle, and (c) knowledge spillovers captured from all other regions. Private innovation investment is not considered in the model, a simplification made for convenience, so we do not have to consider firms' innovation efforts, allowing us to focus on the analysis on the government budget dedicated to innovation.[3]

Government budgets are entirely spent in public R&D investment. Public R&D is broadly divided in basic and applied research (Morales 2004; Park 1998). The main distinction between them is that only applied research can improve technology, but its productivity and results are improved by basic research (Morales 2004). Public R&D yields knowledge spillovers that flow to other regions and positively affect the production technology of firms located therein. Based on the literature discussed previously, we assume that interjurisdictional spillovers represent a higher share of results in the case of basic research, both because it yields more knowledge externalities in general (i.e., the share of results internalized by the R&D-performing firm or institution is smaller) and because a larger share of such externalities spreads geographically, comparing to the case of applied research (Nelson 1959; Gersbach and Schneider 2015; Funk 2002).

In order to maximize net income, the government decides (a) the level of taxation (and therefore of R&D investment), and (b) the composition of the public R&D bundle. To

[2] This tax base was chosen to highlight the state competition and the tradeoff between tax cost and improved product of capital as a result of technological improvement (Zodrow and Mieszkowski 1986; Oates and Schwab 1988; Keen and Marchand 1997). This choice, however, is not critical to the conclusions of the model.

[3] An extension of this model in future research could incorporate this and other factors and assess the potential effects of fiscal decentralization on private decision-making, considering the interactions between private and public investment, along with any substitution (*crowding-out*) or additionality effects.

hypothesize on the potential effects of decentralization, we follow similar analyses (Besley and Coate 2003; Dhillon, Wooders and Zissimos 2007; Feidler and Staal 2012) and compare the optimal government decision in the extreme cases of complete decentralization (regional governments are the only tax authorities and have full discretion to decide on their spending) and a total centralized government (the national government retains full power over public revenue and expenditure).

The main outcomes of the model are determined by the level of knowledge spillovers generated by R&D activities, state competition and capital mobility (according to the Leviathan, or 'race to the bottom' hypothesis) and by new technology developed by public research that counterbalances the cost of taxes by increasing the productivity of capital. The main differences between the centralized and decentralized cases are: (a) regional governments do not consider knowledge spillovers that do not accrue to their own local economy; and (b) subnational governments compete to attract capital, considering the effects of their choices on both the tax cost of capital and technology improvement.

Based on such differences, we extract the two following main propositions from the model about the relation between fiscal decentralization and public R&D investment:

Proposition 1: All other things constant, a higher level of fiscal decentralization should lead to a lower intensity of basic research within the public R&D bundle, as a lower share of its results stays within the region.

The main force driving the optimal composition of the public R&D bundle is the different levels of knowledge spillovers of basic and applied research. The central government decision is not affected by such interregional externalities, as they positively affect the overall country income. Therefore, the central government bases its decision solely on the productivity

parameters of both types of R&D. The regional government, on the other hand, weights such parameters by the level of interregional spillovers applicable to each type of R&D, as its objective is to maximize income within the state or province, and therefore, it does not take into consideration any value generated elsewhere. As basic research yields more interjurisdictional externalities (as assumed), the optimal decision in a decentralized setup is a lower share of basic research within the public R&D bundle. This is the first main prediction of the model to be empirically tested in the next section.

Proposition 2: All other things constant, a higher level of fiscal decentralization should lead to a lower level of public spending on innovation, as a consequence of knowledge spillovers (that reduce regional governments' incentives to invest in R&D) and of state competition to attract capital (that limits the subnational government budget), in spite of the contribution of technology to the regional product.

The optimal level of R&D investment in both cases is affected by three forces: regional spillovers, the negative impact of taxes on both capital investment and available income, and the positive impact of public R&D on the production technology. The first one follows the same reasoning of the composition of the R&D bundle: as the contribution of innovation to the regional product is smaller than to the national output because of interregional externalities (arising from both types of research), subnational governments tend to spend less on R&D. Meanwhile, the same effect is not observed in the centralized setup.

However, when taxes are defined at the regional level, they also influence the level of capital investment in each region. Such effect, however, is ambiguous. The tax cost reduces net capital gain and discourages capital investment, so state competition and capital mobility in the decentralized setup act as a limit to government revenue and spending, following the 'Leviathan

hypothesis' (Brennan and Buchanan 1980). On the other hand, public investment in R&D (financed by taxes) increases both the technology factor and the production, increasing capital earnings and thus attracting additional capital.

As argued by Kappeler and Välilä (2008), the final outcome of these three forces cannot be determined theoretically *a priori*. Nevertheless, we expect innovation spending to be lower in a decentralized environment, as in most cases the negative effects of state competition and interregional spillovers should overcome the benefits of technological improvement within the region. Combined, these forces should cause the tax rate established by the regional government to be lower than the one determined by a centralized tax authority.[4] This constitutes the second prediction to be tested in the empirical analysis described in the next section.

Empirical Analysis

In this section, we present a quantitative analysis to test the two propositions derived from the theoretical model. For such purpose, we investigate whether the level of fiscal decentralization of a country is a significant explanatory variable of both the magnitude and composition of government spending on R&D, after controlling for different economic, demographic, institutional and technological features.

Data

The data used for this empirical analysis were collected from different sources and organized in a panel dataset that contains observations for 47 countries in different years, covering the period 1996–2015.[5] Data on public budget, spending and revenue for each country

[4] Proposition #2 is not just a direct implication or repetition of the Leviathan hypothesis or the 'race to the bottom' argument (Zodrow and Mieszkowski 1986), as the tax cost (and its negative effect on capital attraction) constitutes only one of the forces at play that lead to such conclusion of the model.

[5] List of countries and years presented in Table B3 of Appendix B, along with the mean value of the dependent variables for each country.

were extracted from the *IMF Government Finance Statistics (IMF-GFS)* database (IMF 2014, 2018). Economic, demographic and technological features were gathered from the *World Bank Development Indicators* (World Bank 2019). To control for the level of education or human capital of the population, we use the Education Index of the *Human Development Indices and Indicators* (UNDP 2018). The *IDB Database of Political Institutions* is the source of variables related to the political system and orientation of the party controlling the national executive branch. And an alternative measure for fiscal decentralization (used as robustness check) comes from the *Regional Authority Index* (Hooghe et al. 2016).

However, comparable data on public innovation spending are still not available for many countries, or in many cases there is only information for a limited number of years. Also, our sample is limited to observations (country-year pairs) with at least one positive value for R&D spending (basic or applied). For these reasons, our dataset constitutes an unbalanced panel with missing values for different countries and periods (we discuss this limitation and its implications in further detail below).

The level of fiscal decentralization of a country in a given year is measured using information from the IMF-GFS database. The shares of subnational levels of government in general government revenue (excluded intergovernmental grants) and total public spending are used as indicators of revenue and expenditure decentralization, respectively (we consider these two cases in separate estimates, as they tend to be highly correlated). These definitions or classifications have been criticized for not capturing or reflecting appropriately other relevant dimensions of fiscal decentralization, such as the division of functions between government levels and the political process by which authorities take office (Asatryan, Feld and Geys 2015; Martinez-Vazquez, Lago-Peñas and Sacchi 2017). In spite of such limitations, the same or

similar indicators have been used in different papers (Grisorio and Prota 2015; Kappeler and Välilä 2008; Sacchi and Salotti 2016), and, considering the challenge of summarizing a complex feature in a single variable, they can be accepted as measures to empirically assess the potential effects of fiscal decentralization or its correlation with other features of the government budget. And whereas the IMF-GSF database does not comprise information on the other mentioned dimensions of decentralization (Martinez-Vazquez, Lago-Peñas and Sacchi 2017), on the plus side it provides a larger country sample than other options (Asatryan, Feld and Geys 2015) and standardized and updated data across countries that allows for a comparison and panel analyses, such as the one presented herein.

Empirical Model, Identification Strategy and Robustness Checks

For the specification of the empirical model, we assume that the public R&D budget is determined by all government levels in light of economic, technological and demographic features of the country, the political orientation of the party controlling the executive branch (at the national level), and broader decisions related to the public budget. And as public innovation yields different payoffs for central and regional governments, such decision is also affected by the country's level of fiscal decentralization.

We consider that all variables affect government budget decisions contemporaneously, a specification used in different empirical papers (Arze del Granado, Martinez-Vazquez and McNab 2016; Ashworth, Galli and Padovano 2009; Busemeyer 2007). In addition, we introduce lagged versions of the dependent variables as explanatory ones to account for adjustment costs on budget composition.

We expect decisions on the public R&D budget to be influenced by the level of technological development and weight of high-technology sectors in the economy. To control for

technological disparities between countries, we include the following explanatory variables: (a) number of patent applications per capita filed by residents, as a measure of knowledge stock and development; (b) to account for international competitiveness of national's high-technology industries and for the export contribution of their products and services to the economy, we include an interaction term between international trade and high-tech exports; and (c) share of the population with access to the internet.[6]

On those bases, we use a simple linear reduced-form specification to assess whether the correlation of decentralization with public R&D:

$$y_{it} = \beta' X_{it} + f_i + u_{it} \qquad (1)$$

where y_{it} represents one of the four dependent variables (defined as: the share of basic, applied and total R&D spending in the public budget, and the share of basic research within the public R&D bundle or 'basic research intensity');[7] X_{it} is a vector of control observed variables that influence or are taken into consideration by the government to determine its R&D budget. The estimating model also considers country time-invariant features or fixed effects (f_i), and a non-observed random error term (u_{it}).

The group of explanatory variables (X_{it}) includes a lagged version of the dependent variable (to account for past decisions and control for adjustment costs); the levels of fiscal decentralization (revenue or expenditure) and decentralization vertical imbalance;[8] the size of

[6] We do not to include private R&D investment as an explanatory variable of the model because of endogeneity or feedback effects that could bias the estimates. We also do not include any variables to control for the strength or other features related to the intellectual property regime (IPR) of each country, as recent literature findings failed to find a clear link between IPR and innovation policy (Edler, Cameron and Hajhashem 2015), and between IPR and innovation results (Blind 2016).

[7] Such variables consider public spending at all levels of government jointly. We do not distinguish between national and subnational expenditures (see the definition presented in Table B1 of Appendix B).

[8] This variable was included because different studies have found evidence that the difference between own revenue and own spending at a given level of government (vertical fiscal imbalances or gaps) can affect the public budgets (Eyraud and Lusinyan 2013; Borge and Rattsø 2002). The definition (see Table B1 in Appendix B) follows the one used by Sorens (2016).

government; land area; level of economic activity (GDP, GDP per capita, and level of unemployment); demographic factors (size of the labor force, share of population in urban areas, population density and education index); technological development (number of patent applications per capita filled by residents, internet access, and interaction term between trade and high-tech exports); and variables on the political system and orientation of the national chief executive party (presidential system, parliamentary system, left-wing and right-wing government chief party). In addition, a dummy for member countries of the European Union was included to control for the cooperation for R&D and innovation in the region. The list, definition and sources of all variables used in the empirical analysis are presented in Table B1 of Appendix B, and Table B2 displays the main descriptive statistics for these variables.

We estimate the parameters of Equation 1 using two-step system-GMM (Arellano and Bond 1991; Arellano and Bover 1995; Blundell and Bond 1998), which is largely considered the 'workhorse in estimating dynamic panel data' (Kappeler and Välilä 2008) and has been used in several related studies (Jia, Guo and Zhang 2014; Sacchi and Salotti 2016). When defining the instrumental variables, none of the explanatory variables were assumed to be exogenous, and a set of year dummies was included as exogenous instruments. Considering the gaps in our unbalanced panel, we apply forward orthogonal deviations transformation (Arellano and Bover 1995), and in light of the limited number of observations, we reduce instrument count by collapsing instruments into a column vector instrument (Roodman 2006), applying principal components analysis (Mehrhoff 2009), and reducing the number of lags of the explanatory variables used as instruments. Statistical significance is assessed at a 95 percent confidence level.

Considering the small sample size and limitations of the existing data, we run a number of robustness checks to test whether the results obtained in the main model are sensitive to our

choices of data, identification strategy and model specification. First, considering the limitations of the fiscal decentralization variable and of the IMF-GFS database discussed previously, we run estimates using the indices of regional governments' policy and tax authority (as alternative indicators of expenditure and revenue decentralization, accordingly) published by the *Regional Authority Index - RAI* (Hooghe et al. 2016).[9] Second, as the literature suggests that the two-step GMM might be sensitive to instrument count and choice in the case of small samples (Roodman 2006), we also estimate the coefficients using a fixed effects model. Third, to check whether the heterogeneity of countries in our sample might bias or affect the results, we run a set of estimates considering only countries with a minimum level of economic development, i.e., a GDP per capita higher than US$10,000 (considering the latest observation in the dataset for each one).[10] Finally, we estimate the parameters of Equation 1 multiple times, considering different versions of the vector of control variables X_{it}, gradually excluding each of the explanatory variables, to check if the sign and statistical significance of the fiscal decentralization coefficient remain stable.

Estimation Results

The estimated coefficients of the empirical model and their statistical significance are presented in Table 1, along with the results of the over-identification, serial correlation and sampling adequacy tests. In none of the estimates the AR(2) test rejects the hypothesis of no second-order correlation of differenced residuals, suggesting that the instruments are orthogonal to the error terms. The Hansen and Sargan tests also do not reject exogeneity of the instruments for any of the regressions (at a 95% confidence level). And the Kaiser-Meyer-Olkin test (KMO)

[9] Using these alternative estimators substantially lower the number of available observations (the RAI dataset covers the period up to 2010), and, for this reason, the fixed effects (FE) model is used to estimate the parameters.
[10] We also tried to limit the sample to OECD countries, but the resulting dataset is too small and does not provide a reliable basis to run the estimates.

for sampling adequacy indicates that the principal component analysis reduced the number instruments without losing relevant identifying information. These results indicate that the lagged variables used as instruments efficiently mitigate endogeneity problems, reducing bias and improving consistency of the results.

Table 1. Estimation Results

	Fiscal Decentralization = Expenditure Decentralization				*Fiscal Decentralization* = Revenue Decentralization			
	Dependent Variables				Dependent Variables			
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Public spending on basic R&D	Public spending on applied R&D	Total public R&D spending	Share of basic research in public R&D	Public spending on basic R&D	Public spending on applied R&D	Total public R&D spending	Share of basic research in public R&D
Dependent Variable$_{(t-1)}$	0.974***	0.351***	0.576***	0.960***	0.778***	0.337***	0.620***	0.715***
	(0.036)	(0.044)	(0.072)	(0.092)	(0.094)	(0.086)	(0.065)	(0.084)
Fiscal decentralization	-0.024***	-0.014***	-0.023***	-0.913**	-0.028**	-0.020***	-0.024***	-1.372**
	(0.003)	(0.005)	(0.004)	(0.427)	(0.013)	(0.005)	(0.006)	(0.606)
Decentralization imbalance	0.034***	0.016***	0.029***	0.910*	0.008**	0.006*	0.011***	0.713**
	(0.005)	(0.005)	(0.003)	(0.528)	(0.003)	(0.004)	(0.003)	(0.325)
Unemployment	0.000***	-0.000***	-0.000*	0.007***	0.000***	0.000	-0.000	0.007***
	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.002)
GDP per capita (ll)	0.002***	0.000	0.009***	-0.531	-0.016*	-0.005	-0.019**	-0.274
	(0.001)	(0.000)	(0.002)	(0.448)	(0.009)	(0.007)	(0.008)	(0.662)
Labor force (ll)	0.000	-0.003**	0.000	-0.640	-0.022**	-0.015**	-0.029***	-0.493
	(0.000)	(0.002)	(0.000)	(0.470)	(0.011)	(0.006)	(0.010)	(0.810)
Urban pop.	0.000*	-0.000**	0.000***	0.005*	0.000	-0.000**	0.000*	0.014**
	(0.000)	(0.000)	(0.000)	(0.003)	(0.000)	(0.000)	(0.000)	(0.007)
Land area	0.000***	0.000***	0.000***	-0.000*	0.000	0.000	0.000***	-0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GDP (ll)	-0.001**	0.002**	-0.003***	0.608	0.020**	0.012**	0.026***	0.351
	(0.000)	(0.001)	(0.001)	(0.438)	(0.010)	(0.006)	(0.009)	(0.769)
Party orientation: left wing	-0.001*	0.000	0.000	0.004	-0.001*	0.000	-0.001	-0.030
	(0.000)	(0.000)	(0.001)	(0.021)	(0.001)	(0.001)	(0.001)	(0.028)
Party orientation: right wing	-0.000	-0.000	-0.001	-0.050*	-0.001	-0.001	0.000	0.013
	(0.000)	(0.000)	(0.001)	(0.030)	(0.001)	(0.001)	(0.001)	(0.052)
Pol. system: presidential	0.004	0.007	0.005	0.340	0.003	0.005	-0.000	0.420*
	(0.003)	(0.005)	(0.005)	(0.223)	(0.004)	(0.004)	(0.005)	(0.215)
Pol. System: parliamentary	0.004***	-0.003**	0.002	0.110	0.001	-0.003*	0.003	0.242
	(0.001)	(0.001)	(0.002)	(0.149)	(0.002)	(0.002)	(0.003)	(0.216)

Gov. expenditure as % of GDP	-0.000***	0.000***	0.000	-0.001	0.000	0.000***	0.000	-0.002
	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.003)
Patent app. per capita	0.252	1.401	-8.330**	127.436	4.261	0.223	-2.864	159.122
	(1.600)	(3.094)	(3.719)	(183.534)	(3.276)	(1.795)	(4.628)	(118.980)
Population density	-0.000**	0.000**	-0.000***	-0.000	-0.000**	0.000**	-0.000**	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Internet access	0.000***	-0.000**	0.000	-0.001**	-0.000***	0.000	-0.000**	-0.002**
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
Trade*high-tech. exports	-0.000***	-0.000***	-0.000***	0.000	-0.000*	-0.000***	-0.000***	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Education index	-0.018***	0.018**	-0.038***	0.875**	0.009	-0.006	-0.000	0.976
	(0.005)	(0.008)	(0.011)	(0.439)	(0.009)	(0.011)	(0.010)	(0.608)
EU country dummy	-0.000	0.005**	0.004	-0.035	-0.002	-0.008**	-0.003	-0.152
	(0.001)	(0.003)	(0.004)	(0.102)	(0.003)	(0.003)	(0.005)	(0.118)
Constant	0.000	0.000	0.000	-1.673	-0.045***	-0.015	-0.037	-0.249
	(0.000)	(0.000)	(0.000)	(1.102)	(0.017)	(0.020)	(0.035)	(0.805)
Observations	433	433	433	429	433	433	433	429
No. of countries	42	42	42	41	42	42	42	41
Wald chi-squared	2.640e+07	3.040e+07	70626	23213	38067	3610	54210	27006
Wald p-value	0	0	0	0	0	0	0	0
Sargan stat.	13.52	54.82	55.35	11.53	12.82	49.46	46.93	10.78
Sargan p-value	0.985	0.127	0.139	0.828	0.979	0.101	0.179	0.931
Hansen J-stat	38.18	51.43	36.50	12.55	21.50	20.41	17.02	11.80
Hansen p-value	0.0750	0.206	0.813	0.766	0.664	0.991	0.999	0.894
AR(1) test	0.00197	0.000737	3.00e-05	0.0390	0.00121	0.00478	4.90e-05	0.0848
AR(2) test	0.657	0.374	0.968	0.157	0.606	0.311	0.872	0.119
KMO	0.895	0.744	0.787	0.948	0.945	0.569	0.683	0.965

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments. AR(1), AR(2) are the first and second order autocorrelation tests, and Sargan and Hansen are the overidentification tests. KMO is the Kaiser-Meyer-Olkin measure of sampling adequacy.

The first four columns show the results for the expenditure decentralization analysis. We find evidence that this type of decentralization is negatively correlated with both types of R&D spending: our estimates suggest that an additional percentage point (p.p.) of expenditure decentralization is associated with a reduction of the share of basic R&D in the total public budget of around 0.024 p.p.; in the case of applied R&D, spending decreases around 0.014 p.p.

As a consequence, the share of overall R&D in government spending is also decreased by approximately by 0.023 p.p. (per additional decentralization p.p.), and the composition of the public innovation bundle changes, with a reduction of basic research intensity (share of basic research in public R&D) of around 0.91 p.p.

Revenue decentralization estimates are displayed in columns 5 to 8 of Table 1. Again, we find that decentralization is associated with a decrease of total public innovation investment by a similar magnitude (around -0.024 p.p. of the share of total R&D per each decentralization p.p.) On the other hand, the estimates suggest a higher negative correlation with the basic research intensity (around -1.372 p.p.), indicating potential larger effects on the composition of the public R&D bundle.

Although the fiscal decentralization coefficients in the basic, applied and total R&D spending models seem small (absolute values below 0.03), their economic importance must be assessed in light of their relative magnitude compared to the budget dedicated to each of these activities.[11] As displayed in Table B2 of Appendix B, R&D spending averaged 1.6 percent of the total public budget in our sample, while mean basic and applied R&D expenditures are around 0.8 percent each. Therefore, the -0.023 and -0.024 parameters for decentralization in the 'total R&D' estimates mean that, *caeteris paribus,* we expect public funds dedicated to R&D to decrease approximately 1.6 percent of its original value for each additional p.p. of decentralization of a country's revenue or expenditure. Taking such values into account, our estimates suggest that, in the case of a substantial government reform that decentralizes government expenditures or revenues, e.g., above 10 p.p., the expected reduction in publicly-

[11] The interpretation of parameters for basic research intensity estimates are more straightforward, as they indicate the estimated change of the share of basic R&D spending in the entire government innovation investment.

funded innovation activities is relevant (above 14 percent) and should not be overlooked, as the change in the composition of such activities, as they are likely to be more focused on applied R&D projects (around 9 percent lower basic research intensity).

Results of the robustness checks are presented in Tables B4 to B11 of Appendix B (one for each dependent variable, considering both expenditure and revenue decentralization). We find that, in most cases, the sign and significance of the coefficients of the fiscal decentralization variables confirm the results of the main model. Estimates using the RAI indicators (column 1) present negative and statistically significant coefficients for regional policy and tax authority indices (used as alternative indicators of expenditure and revenue decentralization, respectively) only in the cases of basic and total R&D spending. The fixed effects model (column 2) also confirms our findings only for these cases, suggesting that the results for these two dependent variables are more robust. The estimates using only countries with a GDP per capita above US$ 10,000 (column 3) also produce decentralization parameters that follow the sign and significance of the main model in all but one case (applied R&D and revenue decentralization—Table B9). And in most estimates, the robustness checks using the static version of the model and the alternative vector of control variables (columns 4 to 19) also yield coefficients of decentralization that are aligned with the results of the main model, suggesting that our findings are considerably robust to model specification.

On the other hand, an important shortcoming is that the coefficients of some of the control variables (especially GDP per capita, urban population and internet access) neither present the expected sign nor remain stable across different robustness checks, and it is difficult to interpret their economic meaning. Such problems can be attributed to the small number of

observations and high variance of some variables, causing the coefficients to vary substantially, depending on the estimate and instrument count. We discuss this issue in further detail below.

Discussion of the Findings, Limitations of the Study and Policy Implications

The results of the *empirical* analysis provide support to the two propositions derived from the theoretical model. First, we find evidence that both expenditure and revenue decentralization are negatively and significantly correlated with the share of basic research in the public R&D bundle, suggesting that the decentralization level may affect the composition of the public innovation investment, in accordance with *Proposition #1*. In light of the literature on innovation spillovers, we argue that this result is mainly caused by higher levels of interregional externalities associated with basic research. As described in the theoretical model, subnational levels of government have incentives to invest less in this activity, as it is closer to the case of a global public good, with a high share of spillovers flowing to other regions. Governments at the national level, on the other hand, do not differentiate between such externalities and localized results, since they both affect national output, regardless of where research takes place.

The empirical analysis also supports the hypothesis that total government spending on innovation is negatively affected by both revenue and expenditure decentralization. Although the theoretical model does not predict such outcome unambiguously, it is the most likely result, as expressed in *Proposition #2*. The theoretical model explains the economic drivers of this result: interregional spillovers and state competition reduce the payoffs and incentives for state governments to invest in R&D (in comparison with the central government), in spite of the benefits of locally-performed research. This finding is at odds with the 'race to the top' hypothesis suggested by the literature on fiscal decentralization and composition of public budget (Keen and Marchand 1997). Our study suggests that the incentives of regional

governments to spend more on productive activities to attract capital (Grisorio and Prota 2015; Sacchi and Salotti 2016) can be offset by considerable levels of interregional spillovers in the case of ST&I activities.

Overall, the results provide supporting evidence to the general idea that the level of fiscal decentralization of a country is correlated and can affect public innovation spending. The results are in line with previous research showing that innovation presents high levels of spillovers that are not geographically bounded (Bernstein and Nadiri 1989; Bloom, Schankerman and Van Reenen 2013) and that basic research yields more results that are not internalized within regions (Funk 2002).

However, this empirical analysis has limitations (many of which have been pointed out throughout the paper), which means that the evidence presented must be considered with proper caution. The main limitations include the size of the dataset and the potential weaknesses of the indicators used to test the hypotheses. The availability of data for a small number of countries affects the significance of the coefficients, as the two-step GMM estimator produces better results with a large number of groups (Roodman 2006). Still, the sign and significance of the decentralization coefficients are considerably robust (especially in the cases of basic and total R&D spending). However, we do not find a stable set of coefficients for some of the control variables, suggesting that they are sensitive to model specification or to the sample size used for the analysis. In addition, the sample does not include countries that are important cases to discuss the effects of decentralization (such as the U.S., China and India). Again, future research may be able to include these economies. Besides, the indicators used for fiscal decentralization—and which have been commonly used in the vast literature on the impacts of decentralization (Martinez-Vazquez, Lago-Peñas and Sacchi 2017)—do not necessarily reflect the division of

government functions in fostering or investing in science and technology activities. Finally, although this empirical analysis relies on the best available data at country level, the propositions derived from the theoretical model are based on the idea that national and regional governments have different solutions to their maximization problems. For this reason, testing the propositions distinguishing between both government levels (as data on R&D public spending become available) would be an important extension of this study.

Acknowledging these limitations, this paper still provides a first argument and pretty robust evidence of the link between fiscal decentralization and public R&D, a novel finding and relevant contribution to both the fiscal decentralization and innovation policy literature. It opens a research agenda for future studies to obtain additional data, overcome the mentioned shortcomings and test the proposed hypotheses or suggest new ones.

Two main relevant policy implications follow from our findings. First, deepening fiscal decentralization should be considered along with measures to compensate for the expected decreases in innovation spending. Our results suggest that this reduction can be large in the case of a substantial decentralization reform, providing a first estimate of its magnitude to be considered for policy analysis. The literature indicates different paths to address this problem, including a system of taxes and subsidies to compensate for public R&D investment at the state level (Oates 2008a) and Coase-type bargaining between provinces (Hulten and Schwab 1997).

The second main implication refers to the roles and responsibilities of different levels of government in the design of national strategies for ST&I. The division of functions—or expenditure assignments—is a central topic to the design of fiscal decentralization systems and emphasized early in Oates's decentralization theorem. Our findings suggest that, in light of different levels of interregional spillovers, the responsibility to finance or carry out basic

research should be higher for central levels of governments, leaving state authorities with the role of promoting more applied research and development.

Concluding Remarks

In the last decades, a large literature has presented evidence of the benefits of fiscal decentralization in a number of policy areas, including education (Faguet 2004), health services (Habibi et al. 2003) and infrastructure (Kappeler and Välilä 2008). This paper discusses the relation between fiscal decentralization and spending on public R&D, a topic that has not been properly addressed by this literature. It contributes to the existing knowledge by explaining how decentralization may affect the size and composition of public innovation investment.

We present a model of a closed economy where states compete for capital investment and public innovation spending improves production technology locally, but part of its results flows to other regions. Based on this theoretical framework, we hypothesize that decentralized governments dedicate a smaller share of their R&D budget to basic research and that their overall innovation investments are smaller in most cases. Such propositions are tested through a novel empirical analysis using panel data across countries. The results provide empirical support to the mentioned hypotheses, as we find evidence that higher levels of both expenditure and revenue decentralization are associated with a lower intensity of basic research in public R&D and with a lower level of R&D spending

The empirical investigation, however, has important limitations because of the small size of the dataset, shortcomings of the indicators used for fiscal decentralization and absence of data of R&D spending at the state level. For these reasons, this paper represents a first investigation on the subject, opening a promising research agenda on the links between fiscal decentralization

and innovation policy. As more and better data become available, future studies can improve the empirical analysis and serve as a check on the robustness of our empirical findings.

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Appendix A. Theoretical Model

Basic Setup

We consider a model with discrete time periods ($t = 1, 2, ...m$) and a closed economy divided in a large number of n symmetric regions, with only one homogeneous final good sold at the same competitive price (set at one for simplicity) and produced by n firms, one located in each region. We abstract from changes in population by assuming a constant number of uniformly distributed and non-mobile individuals (Oates and Schwab 1988). Capital, on the other hand, is perfectly mobile across jurisdictions, and it is allocated by its owners in each period to maximize earnings. The total stock of capital in this society ($\overline{K}$) is fixed in the short run (Oates and Schwab 1988, Zodrow and Mieszkowski 1986), and its ownership is evenly distributed among all individuals, so that constituents of each region own $\overline{K}/n$ units of capital. Gross regional output in region i at period t depends on the capital k_{it} invested in the firm located therein and on the production technology level A_{it} of each firm, following a standard Cobb-Douglas production function.

Firms compete to attract capital by paying an interest rate r_t $(0 < r_t < 1)$. In addition, firms have to pay taxes that are levied on each unit of capital invested in the respective period, according to a tax rate z_{it} set by the government.[1] As suggested by Dhillon, Wooders, and Zissimos (2007), taxes are levied on capital used within the jurisdiction ('destination basis'), regardless of its origin. The value of firms' output that is not used to pay interest and taxes adds to the income of the respective region.

[1] This tax base was chosen to highlight the state competition and the tradeoff between tax cost and improved product of capital as a result of technological improvement. This choice, however, is not critical to the conclusions of the model. A similar tax base was also used in previous models (Zodrow and Mieszkowski 1986, Oates and Schwab 1988, Keen and Marchand 1997).

In this scenario, the net income of a region is given by the gross output minus taxes and interest paid by the firm, plus interest received by capital owners in the region, as presented in Equation A1:

$$y_{it} = k_{it}^{\alpha} A_{it}^{1-\alpha} - k_{it}(z_{it} + r_t) + (\overline{K}/n)r_t;\ 0 < \alpha < 1 \qquad \text{(A1)}$$

As Equation A1 provides for diminishing returns of factors, firms will take additional capital up to the point where its marginal product net of taxes equals its cost (the applicable interest rate), as suggested by Oates and Schwab (1988):

$$\frac{\partial y_{it}^{c}}{\partial k_{it}} = 0 \rightarrow \alpha \left(\frac{A_{it}}{k_{it}}\right)^{1-\alpha} - z_{it} = r_t \qquad \text{(A2)}$$

Both the central and regional public budgets (G_{it}) are balanced, so there is no public savings or deficit,[2] and they are entirely spent in public R&D investment. We assume that the central government spends all taxes in the same region where they are collected, so we can abstract from regional transfers. The public spending constraint for each region in each period is therefore:

$$G_{it} = k_{it} z_{it} \qquad \text{(A3)}$$

Firms in all regions begin at the same technology level $A_{i,t-1}$, so we do not have to consider initial regional disparities. Their state of technology evolves according to (a) the investment made by the government in R&D within the region (G_{it}), (b) the composition of public R&D spending, and (c) knowledge spillovers captured from R&D performed in all other regions ($h(.)$), as presented in Equation A4. R&D is broadly divided in basic and applied research (Morales 2004, Park 1998) according to the variable b_{it} $(0 < b_{it} < 1)$, that informs the share of

[2] This is a standard assumption used strictly for convenience in similar models (Zodrow and Mieszkowski 1986, Dhillon, Wooders, and Zissimos 2007).

public R&D devoted to basic research as set by the government. Similarly, spillovers from other regions can be divided in basic and applied knowledge. In order to preserve the tractability and simplicity of the model, spillovers only affect the technology state directly, with no second order impacts on the results of locally-performed R&D.

$$\Delta A_{it} = A_{it} - A_{i,t-1} = G_{it} f(b_{it}) + \sum_{J=1}^{n-1} G_{Jt} h(b_{Jt}) \,;\, J \neq i \quad \text{(A4)}$$

The main distinction between basic and applied research considered herein is that basic research generates the knowledge necessary for innovations, but it does not improve the technology by itself, so further applied research is required to apply such knowledge to the production process (Auerswald et al. 2003, Morales 2004). Investment in applied research, on the other hand, is a sufficient condition to improve technology, but its productivity and results are improved by basic research knowledge. This description suggests the following functional form for the R&D productivity factor:[3]

$$f(\, b_{it}) = (1 - b_{it})\big(\theta(1 - s_A) + b_{it}\gamma(1 - s_B)\big) \qquad \text{(A5)}$$

where

$$\gamma > \theta > 0 \qquad \text{(A5a)}$$

$$s_B > s_A > 0 \qquad \text{(A5b)}$$

The positive parameter θ represents the productivity of applied research, γ is the contribution of basic research to productivity improvement (the inequality in Equation A5a represents the productivity increase of applied R&D caused by basic research). s_B and s_A are the levels of interregional spillovers of basic and applied research, respectively. Based on the literature discussed previously, we assume that interjurisdictional spillovers represent a higher

[3] This functional form is based on the specification of basic and applied research suggested by Morales (2004) and the effect of spillovers defined by Feidler and Staal (2012).

share of results in the case of basic research (Equation 5b), both because it yields more knowledge externalities in general (i.e., the share of results internalized by the R&D-performing firm or institution is smaller), and because a larger share of such externalities spreads geographically, comparing to the case of applied research (Nelson 1959, Gersbach and Schneider 2015, Funk 2002).

In addition, these parameters take the same value for all regions,[4] and spillovers are equally distributed among all regions (other than the one producing them), so that each receives an equal share of externalities arising from R&D performed in all other *n - 1* jurisdictions. As regions are assumed to be similar, the spillover factor in Equation A4 can be simplified, as presented in Equation A6.

$$\sum_{J=1}^{n-1} G_{Jt} h(b_{Jt}) = \sum_{J=1}^{n-1} G_{Jt} \left(\left(\frac{1}{n-1} \right) (1 - b_{Jt}) \left(\theta(s_A) + \gamma b_{Jt}(s_B) \right) \right) = \qquad \text{(A6)}$$

$$G_{jt}(1 - b_{jt}) \left(\theta(s_A) + \gamma b_{it}(s_B) \right); j \in J$$

The Regional Government Decision

We first consider the case of complete decentralization, where regional governments are the only tax authorities and have full discretion to decide on their spending. The government aims to maximize net local income, as provided in Equation A1. To achieve this goal, it taxes locally-invested capital and spends its budget on public R&D, determining the composition of its investment bundle.

While establishing the applicable tax rate, regional governments have to consider the impact of their decisions on capital investment. As capital is perfectly mobile and there is a large

[4] This assumption would be relaxed in case of more than one final good or production sector (which implies different technologies and spillover levels), or if regions had different industrial property regimes for protection of invention (that could also affect externalities). These extensions are not dealt with herein.

number of communities, competition equalizes such rate among all jurisdictions (Zodrow and Mieszkowski 1986, Dhillon, Wooders, and Zissimos 2007), so firms and governments are 'price takers' (Equation A7). Considering the relation between marginal product of capital, taxes and interest rates expressed in Equation A2, the exogenous interest rate determines the capital constraint of the regional government's maximization problem (Equation A8):

$$r_t = \bar{r}^R \qquad \text{(A7)}$$

$$\alpha \left(\frac{A_{it}}{k_{it}}\right)^{1-\alpha} - z_{it} = \bar{r}^R \qquad \text{(A8)}$$

The regional government trade-off concerning the tax rate can be described as follows: while taxes provide funding for public R&D that improves the production technology (A_{it}) and increases output (Equation A4), they negatively impact the net income through two effects: (a) by reducing the available income (Equation A1); and (b) by reducing the marginal product of capital (Equation A2). The level of taxation is then chosen to maximize local net income according to Equation A1, subject to the budget and capital constraints in Equations A3 and A8, and the expected technology improvement in the province (Equation A4). Interregional knowledge spillovers affect the regional government's decision because they reduce the share of benefits arising from such improvement that stays within the region, as returns that flow elsewhere are not considered in the maximization problem of subnational authorities. Such effect is represented by the spillover parameters (s_A and s_B) in the regional R&D productivity factor (f_i^R) in Equation A5, that reduce the returns of the technological development (Equation A4).

Taking the first order conditions and solving the system of equations, we find the optimal tax rate of the regional government (z_i^{R*}).

$$\frac{\partial y_{it}^c}{\partial z_{it}} = 0 \rightarrow z_i^{R*} = \left((1-\alpha) f_i^{R*} \bar{r}^R\right)^{1-\alpha} \alpha^{\alpha} - \bar{r}^R \qquad \text{(A9)}$$

$$f_i^{R*} = (1 - b_i^{R*})\left(\theta(1 - s_A) + \gamma b_i^{R*}(1 - s_B)\right) \qquad \text{(A9a)}$$

The first term on the right side of Equation A9 represents the optimal marginal product of capital, that is affected both by the technology level and the applicable interest rate. The R&D productivity factor (f_i^R) positively affects the optimal choice of public innovation investment, indicating the negative effect of interjurisdictional spillovers. Equation A9 also informs how the optimal tax rate is affected by competition in the capital market. Such impact is two-folded and non-linear, as suggested by the presence of the interest rate ($\bar{r}^R$) in both terms on the right side of the equation. On the one hand, state competition limits the tax rate: an interest rate increase would have to be partially offset by a reduction of taxes by regional governments, to avoid capital flight and decrease of output. But part of such increase is compensated by maintaining public R&D spending, that raises the gross marginal product of capital. As a result, the tax reduction is not equivalent to the interest rate increase.

To decide on the composition of the public R&D bundle, the government considers the expected technology improvement caused by additional units of basic and applied research, and the respective impact on output. Again, spillovers affect such decision because part of the new developed technology cannot be appropriated and therefore does not generate additional income in the region. The optimal composition of the public R&D bundle (b_{it}^{R*}) is obtained by maximizing the technology level in Equation A4 with respect to the share of basic research (b_{it}).[5] The optimal choice (b_i^{R*}) displayed in Equation A8 is positively correlated with the contribution of basic research (γ), and negatively correlated with the applied research productivity parameter

[5] It can be proved algebraically that $\frac{\partial y_{it}}{\partial f^R} > 0$ for all non-negative values of z_i^R, so an increase in the technology parameter f_i^* positively affects output in all relevant cases.

(θ). As expected, the influence of these factors is reduced by the respective interjurisdictional spillovers, as these results are not accounted for by regional governments in their decision.

$$\frac{\partial A_{it}}{\partial b_{it}} = 0 \Longrightarrow b_i^{R*} = \frac{1}{2} - \frac{\theta(1-s_A)}{2\gamma(1-s_B)} \qquad \text{(A10)}$$

The Central Government Decision

We now consider the decision of the central government in a scenario of total centralization of both the tax policy and public expenditure. In this case, the government aims to maximize net national income (y_t^C). To achieve this goal, it sets a single applicable tax rate and composition of the public R&D bundle for all regions ($z_{it}=z_{jt}=z_t$ and $b_{it}=b_{jt}=b_t$). As all capital is owned by and equally distributed to individuals within the country, capital compensation payments are offset by the respective interest revenue. Considering the assumption of similar regions, the net national income can be expressed using the case of a representative region, so we can compare the optimal choices of the central government and of regional authorities.

$$y_t^C = \sum_{I=1}^{n}(k_{It}^{\alpha}A_{It}^{1-\alpha} - k_{It}(z_t + r_t) + (\overline{K}/n)r_t) = n(k_{it}^{\alpha}A_{it}^{1-\alpha} - k_{it}z_{it})\ ;\ i \in I \qquad \text{(A11)}$$

The first main difference between the centralized and decentralized cases is the capital constraint. For the central government, the level of capital is constrained only by the total stock available in the economy ($\overline{K}$), assumed to be fixed in the short run. As subnational governments do not have any policy instrument to compete, capital is equally invested across all regions:

$$\bar{k} = \sum_{i=0}^{n} k_{it} \rightarrow\ k_{it} = \frac{\bar{k}}{n} \qquad \text{(A12)}$$

The second difference is the technology function. The central government does not differentiate between interjurisdictional knowledge spillovers and internal (or local) results, as the value that does not accrue to the firm in one region improves the production technology in all

others, so there is no loss (or gain) at the national level. This effect is represented by the sum of all regional outputs in Equation A11. A different way to understand this is to apply the national rates to the spillover and R&D productivity functions (Equations A5 and A6), and substitute it in the R&D Equation A4. The similar regions assumption ensures that the value of externalities flowing out of each jurisdiction is equivalent to spillovers captured from all other areas, and also that the technology development is the same in all regions ($A_{it}=A_{jt}=A_t$). This leads to the technology improvement function presented in Equation 13, which does not contain the spillovers parameters:

$$A_t = A_{t-1} + G_{it}f(b_{it}) + \sum_{J=1}^{n-1} G_{Jt}h(b_{Jt}) = A_{t-1} + (\bar{k}/n)z_t(1-b_{it})(\theta + b_{it}\gamma) \quad \text{(A13)}$$

The optimal level of taxation (z_t^{C*}) is obtained by maximizing the national output in Equation A11, subject to the capital constraint and the expected technology improvement (Equations A12 and A13, respectively). The optimal rate (displayed in Equation A14) increases both with capital availability and the R&D productivity factor (as it raises the marginal product of public innovation), and it decreases with the initial level of technology (because of diminishing returns in the production function).

$$\frac{\partial y_t^c}{\partial z_t} = 0 \rightarrow z^{C*} = (1-\alpha)^{\frac{1}{\alpha}}(f^{C*})^{\frac{1-\alpha}{\alpha}} - \frac{A_{i,t-1}}{(f^{C*})(\bar{k}/n)} \qquad \text{(A14)}$$

$$f^{C*} = (1-b^{C*})(\theta + \gamma b^{C*}) \quad \text{(A14a)}$$

A third feature that distinguishes the centralized government case is the compensation paid to capital owners. Although firms in different regions still compete for capital, they are subject to the same marginal product of capital (because they have the same technology level) and tax rate. In this scenario, the applicable interest rate is a function of total capital availability and of the tax rate set by the central government, as presented in Equation A15. This rate tends to

be lower than the one in the decentralized case, as there is no state competition pushing it upward.

$$r^{C*} = \alpha\left(\frac{A_{it}^{C*}}{\bar{k}/n}\right)^{1-\alpha} - z^{C*} = \frac{A_{i,t-1}}{(f^{C*})\left(\bar{k}/n\right)} - \left(f^{C*}(1-\alpha)\right)^{\frac{1-\alpha}{\alpha}}(1-2\alpha) \quad \text{(A15)}$$

where

$$r^{C*} < \bar{r}^{R} \qquad \text{(A15a)}$$

If we substitute such value in Equation A14, we obtain a different expression for optimal taxes (Equation A16), that can be directly compared to the regional government decision in Equation A9). The first term on the right side of Equation A16 represents the marginal product of capital, that is not affected by the applicable interest rate (unlike the decentralized government case).

$$z^{C*} = \alpha\left(f^{C*}(1-\alpha)\right)^{\frac{1-\alpha}{\alpha}} - r^{C*} \qquad \text{(A16)}$$

The central government's optimal choice for the composition of the public R&D bundle is the one that maximizes technological development in Equation A13, and, consequently, net national output. Equation A17 follows closely the specification of the best choice of the decentralized government (Equation A10), but excluding the parameters of externalities that flow to other provinces.

$$\frac{\partial A_t}{\partial b_t} = 0 \rightarrow b^{C*} = \frac{1}{2} - \frac{\theta}{2\gamma} \qquad \text{(A17)}$$

Effects of Decentralization

Proposition 1: $b^{C*} > b^{R*}$. All other things constant, a higher level of fiscal decentralization should lead to a lower intensity of basic research within the public R&D bundle, as a lower share of its results stays within the region.

This proposition can be derived from the optimal choices of share of basic research presented in Equations A10 and A17. Considering the assumptions presented in Equations A5a (basic research increases applied R&D productivity) and A5b (higher levels of interregional externalities of basic research), it follows that $b^{C*} > b^{R*}$. The central government decision is not affected by interregional externalities (parameters s_A and s_B), as they positively affect the overall country income. The regional government, on the other hand, weights the productivity parameters of each type of R&D by the respective levels of spillovers, as suggested by Equation A10. Subnational authorities choose a lower share of basic research because a lower proportion of the results stays within the region.

Proposition 2: $z^{C*} > z^{R*}$*. 'Ceteris paribus', a higher level of fiscal decentralization should lead to a lower level of public spending on innovation, as a consequence of knowledge spillovers (that reduce regional governments' incentives to invest in R&D) and of state competition to attract capital (that limits the subnational government budget), in spite of the contribution of technology to the regional product.*

The optimal choices for taxation and R&D investment are presented in Equations A9 (regional government) and A16 (central government). The decisions are mostly based on three forces: regional spillovers, the negative impact of taxes (on capital investment and available income), and the positive impact of public R&D on the production technology. Regional spillovers reduce the R&D productivity factor and regional governments' incentives to invest in R&D (Equation A9a), while the same effect is not observed for the central government (Equation A14a) - it is easy to see that $f^{C*} > f^{R*}$. In addition, taxes influence the level of capital investment when they are defined at the regional level, as suggested by presence of the interest rate parameter in Equation A9. They reduce the marginal product of capital (Equation A8),

discouraging capital investment in the region and acting as a limit to government revenue and spending.[6] But public R&D paid by taxes acts a counterforce to this effect, as it improves technology and increases production and capital earnings. In the case of centralized setup (Equation A16), competition for capital investment does not influence the government decision, as taxes are equally applicable to all regions.

It is not possible to state unambiguously in which case the public R&D investment will be higher, as this depends on the value of the parameters in Equations A9 (z^{R*}) and A16 (z^{C*}). Our model, therefore, confirms the argument presented by Kappeler and Välilä (2008) that the final outcome cannot be determined theoretically *a priori.* Still, we understand that, in most cases, the negative effects of interregional spillovers and state competition on R&D spending should overcome the positive incentives of technological innovation, leading to a lower investment level in the case of a decentralized authority.

[6] This is represented by the interest rate variable in the first term of the decentralized government optimal tax rate (Equation A9).

Appendix B. Variables and Robustness Checks of the Empirical Analysis

Table B1. List, Definition and Source of the Variables Used in the Empirical Study

Dependent Variables		
Variable	Definition	Source
Public spending on basic R&D	Share of basic research spending in the total public budget	*IMF Government Finance Statistics (IMF 2018)*
Public spending on applied R&D	Share of 'applied research and development' spending in the total public budget[a]	
Total public R&D spending	Share of overall R&D spending (including basic research, applied research and development) in the public budget	
Share of basic research in public R&D	Share of basic research in the public R&D budget	
Fiscal Decentralization Variables		
Variable	Definition	Source
Expenditure Decentralization	Share of subnational levels of government in general public spending	*IMF Government Finance Statistics (IMF 2018)*
Revenue Decentralization	Share of subnational levels of government (excluded intergovernmental grants) in general public revenue	
Decentralization Imbalance	Difference between expenditure and revenue decentralization levels	
Other Explanatory Variables		
Variable	Definition	Source
GDP (ll)	GDP-constant 2010 US$ (log-linearized)	*World Bank Development Indicators (WB 2019)*
GDP per capita (ll)	GDP per capita- constant 2010 US$ (log-linearized)	
Land area	Land area (sq. km)	
Labor force (ll)	Labor force, total (log-linearized)	
Unemployment	Unemployment, total (share of total labor force unemployed*100)	
Population density	Population density (people per sq. km of land area)	
Urban pop.	Urban population (as share of total population*100)	
Internet access	Individuals using the Internet (as share of total population*100)	
Patent app. per capita	Patent applications by residents divided by total population	
Trade*high-tech. exports	Interaction term: trade (sum of exports and imports of goods and services as a share of GDP) multiplied by high-technology exports (as a share of manufactured exports)	
Gov. expenditure as % of GDP	Size of government (public expenditure as share of country's GDP*100)	*IMF Government Finance Statistics (IMF 2018)*

Education index	"Average of mean years of schooling (of adults) and expected years of schooling (of children), both expressed as an index obtained by scaling with the corresponding maxima" (UNDP 2018).	*Human Development Indices and Indicators (UNDP 2018)*
Party orientation: left wing[b]	Dummy for left-wing orientation of the national chief executive party with respect to economic policy. "Left: for parties that are defined as communist, socialist, social democratic, or left-wing" (Cruz, Keefer, and Scartascini 2018).	*IDB Database of Political Institutions (Cruz, Keefer, and Scartascini 2018)*
Party orientation: right wing[b]	Dummy for right-wing orientation of the national chief executive party with respect to economic policy. "Right: for parties that are defined as conservative, Christian democratic, or right-wing" (Cruz, Keefer, and Scartascini 2018).	
Pol. system: presidential[c]	Dummy for presidential system, i.e., "systems with unelected executives" or "Systems with presidents who are elected directly or by an electoral college (whose only function is to elect the president), in cases where there is no prime minister" (Cruz, Keefer, and Scartascini 2018).	
Pol. System: parliamentary[c]	Dummy for parliamentary system, i.e., "countries in which the legislature elects the chief executive […], with the following exception: if that assembly or group cannot easily recall him […]" (Cruz, Keefer, and Scartascini 2018).	
EU country dummy	Dummy for member countries of the European Union (on August 2019)	European Union (2019)

Alternative Indicators for Fiscal Decentralization

Variable	Definition	Source
Regional government policy authority	The range of policies for which a regional government is responsible. The index ranges from 0 to 4, according to the classification described in the RAI Codebook (Hooghe et al. 2016).	*Regional Authority Index* (Hooghe et al. 2016)
Regional government tax authority	The extent to which a regional government can independently tax its population. The index ranges from 0 to 4, according to the classification described in the RAI Codebook (Hooghe et al. 2016).	

[a] Sum of all values labeled as 'applied R&D' (applied research and development) for all broad spending categories.
[b] Dummy variable for center orientation of the chief executive party not included to avoid perfect collinearity.
[c] Dummy variable for Assembly-elected President not included to avoid perfect collinearity.

Table B2. ***Descriptive Statistics of the Variables Used in the Empirical Study***

Variable	n	Mean	Std. Dev.
Public spending on basic R&D	433	0.008	0.007
Public spending on applied R&D	433	0.008	0.006
Total public R&D spending	433	0.016	0.009
Share of basic research in public R&D	433	0.478	0.320
Expenditure Decentralization	433	0.273	0.131
Revenue Decentralization	433	0.136	0.085
Decentralization Imbalance	433	-0.136	0.083
GDP (ll)	433	26.103	1.539
GDP per capita (ll)	433	10.113	0.792
Land area	433	2.62e+05	8.57e+05
Labor force (ll)	433	15.277	1.264
Unemployment	433	8.791	4.841
Population density	433	149.257	201.207
Urban pop.	433	71.434	13.100
Internet access	433	62.167	23.976
Patent applications per capita	433	0.0002	0.0004
Trade*high-tech. exports	433	1696.292	2056.900
Gov. expenditure as % of GDP	433	44.194	7.684
Education index	433	0.819	0.066
Party orientation: left wing	433	0.316	0.466
Party orientation: right wing	433	0.370	0.483
Pol. system: presidential	433	0.136	0.343
Pol. System: parliamentary	433	0.815	0.389
EU country dummy	433	0.838	0.369
Regional government policy authority	217	1.560	1.373
Regional government tax authority	217	1.023	1.373

Source: calculated by the authors based on IMF (2018); WB (2019); UNDP (2018); Cruz, Keefer, and Scartascini (2018); Hooghe et al. (2016); and European Union (2019)

Table B3. List of Countries and Years Considered in the Empirical Study; Mean Value of the Dependent Variables for Each Country.

Country	Years	Mean public spending on basic R&D	Mean public spending on applied R&D	Mean total public R&D spending	Mean share of basic research in public R&D
Albania	2014-2015	0.000	0.003	0.003	0.000
Austria	2009-2017	0.010	0.016	0.025	0.390
Belgium	2004-2017	0.020	0.004	0.024	0.816
Bulgaria	1996, 2009-2014	0.006	0.000	0.006	1.000
Croatia	2003-2017	0.002	0.002	0.004	0.644
Cyprus	2007-2010, 2012-2017	0.000	0.014	0.014	0.000
Czech Republic	2009-2017	0.005	0.022	0.026	0.177
Denmark	1999-2000, 2009-2017	0.027	0.003	0.030	0.890
El Salvador	2015-2017	0.000	0.010	0.010	0.000
Estonia	1996-1997, 2007-2016	0.011	0.014	0.025	0.440
Finland	2002-2017	0.017	0.011	0.028	0.615
France	1996-2017	0.009	0.017	0.026	0.332
Greece	2002-2011, 2013-2017	0.000	0.010	0.010	0.000
Hungary	2000-2002, 2004-2014, 2016-2017	0.009	0.003	0.013	0.726
Iceland	2014-2016	0.002	0.009	0.011	0.217
Ireland	1996-2017	0.004	0.006	0.010	0.405
Israel	2014-2017	0.003	0.005	0.008	0.333
Italy	2007-2011, 2014, 2016-2017	0.006	0.005	0.011	0.538
Japan	2006-2017	0.003	0.005	0.008	0.340
Kazakhstan	2011, 2013-2017	0.003	0.002	0.005	0.667
Kyrgyz Republic	2015-2017	0.000	0.003	0.003	0.000
Latvia	2002-2017	0.008	0.002	0.010	0.816
Lithuania	2001-2017	0.004	0.008	0.012	0.388
Luxembourg	2015-2017	0.010	0.012	0.022	0.463
Malta	2008-2015	0.000	0.011	0.011	0.000
Moldova	2016	0.003	0.003	0.007	0.500
Mongolia	2017	0.000	0.040	0.040	0.000
Netherlands	1996-2017	0.012	0.011	0.023	0.515
Norway	1996-2017	0.011	0.011	0.022	0.494
Poland	2003-2017	0.006	0.005	0.011	0.558
Portugal	1996-2000, 2002-2014, 2016-2017	0.005	0.010	0.015	0.362
Romania	2005-2017	0.001	0.010	0.011	0.056

Russian Federation	2015	0.000	0.000	0.000	0.000
Slovak Republic	2002-2017	0.014	0.000	0.014	1.000
Slovenia	2000-2011	0.012	0.010	0.022	0.553
South Africa	2013-2017	0.005	0.002	0.007	0.750
Spain	2009-2017	0.006	0.005	0.011	0.522
Sweden	2002-2017	0.027	0.003	0.030	0.897
Thailand	2014, 2016	0.000	0.005	0.005	0.000
Turkey	2016-2017	0.003	0.003	0.006	0.667
Ukraine	2015-2017	0.000	0.003	0.003	0.000
United Kingdom	2008-2017	0.000	0.012	0.012	0.000

Source: calculated by the authors based on IMF (2018); WB (2019); UNDP (2018); Cruz, Keefer, and Scartascini (2018); Hooghe et al. (2016); and European Union (2019)

Table B4. Robustness Check: Expenditure Decentralization; Dependent Variable: Public Spending on Basic R&D

Independent Variables	RAI indicator	Fixed Effects	GDP per capita>10k	Static model	Alternative specifications of the vector of control variables (system GMM)														
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep. Var.$_{(t-1)}$	0.631***	0.72***	0.88***		0.93***	0.87***	0.99***	0.94***	0.89***	0.96***	0.99***	0.94***	0.93***	0.92***	0.98***	0.93***	0.94***	0.99***	0.95***
	(0.072)	(0.03)	(0.03)		(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)
Fiscal decentralization		-0.02***	-0.02***	0.03***	-0.02***	-0.01***	-0.02***	-0.01***	-0.02***	-0.02***	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***	-0.00***	-0.00***	-0.00***	-0.00***
		(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Decentralization imbalance		0.02***	0.02***	-0.04***	0.03***	0.02***	0.03***	0.02***	0.02***	0.02***	0.02***	0.02***	0.01***	0.01***	0.02***	0.01***	0.01***	0.01***	0.01***
		(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Trade*high-tech. exports	-0.000	0.00	-0.00***	-0.00	-0.00***	-0.00	0.00***	-0.00***	-0.00	-0.00	-0.00*	-0.00***	-0.00**	-0.00**	-0.00***	-0.00***	-0.00***	0.00***	
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
Party orientation: left wing	0.000	-0.00	-0.00	0.00	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00	-0.00***	-0.00***	-0.00***	0.00***	-0.00		
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Party orientation: right wing	0.000	-0.00	-0.00	-0.00***	-0.00***	-0.00	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	0.00***	0.00***	0.00***		
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Urban pop.	0.000	-0.00**	0.00***	0.00***	0.00***	-0.00	-0.00***	0.00	0.00	0.00**	0.00	0.00***	-0.00**	-0.00**	0.00***	0.00***			
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
Land area	-0.000	-0.00	0.00*	-0.00*	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***				
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
Pol. system: presidential			0.01	-0.01	0.00**	0.00**	0.00	0.00***	0.01***	0.00**	0.00	-0.00***	-0.00**	-0.00**					
			(0.02)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Pol. System: parliamentary	-0.000	-0.00	0.00***	0.01**	0.00***	0.00*	0.00***	0.00***	0.00**	0.01***	0.00***	0.00**	0.00**	0.00***					
	(0.003)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Patent app. per capita	-1.321	0.78	7.57***	0.96	0.78	0.63	-1.07	3.52***	1.05**	-0.07	0.48	1.25	1.73***						
	(3.193)	(1.74)	(1.53)	(1.29)	(1.33)	(2.34)	(0.89)	(0.47)	(0.42)	(0.44)	(0.69)	(0.82)	(0.42)						
Unemployment	0.000***	0.00*	0.00	0.00*	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00**	0.00***							
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
GDP (ll)	0.010	0.00	-0.00*	-0.00	-0.00***	0.00	0.00	0.00***	0.00***	0.00***	0.00*								
	(0.012)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)								
Internet access	-0.000	-0.00***	-0.00*	-0.00	0.00	0.00	0.00	-0.00	-0.00***	-0.00***									
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
Labor force (ll)	-0.004	-0.00	0.00	0.00	0.00	-0.00	0.00	-0.00***	-0.00***										
	(0.008)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)										
Education index	0.002	0.00	0.00	-0.02**	-0.02***	-0.01*	0.00	-0.01***											
	(0.008)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)											
GDP per capita (ll)	-0.007	-0.00	0.00	0.00	0.00***	0.00	0.00												
	(0.010)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)												
Population density	-0.000	0.00	-0.00***	-0.00***	-0.00***	-0.00													
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
Gov. expenditure as % of GDP	-0.000**	-0.00	-0.00***	-0.00***	-0.00***														
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)														
EU country dummy			0.00	0.00															
			(0.01)	(0.00)															
Regional government policy authority	-0.005***																		
	(0.002)																		
Constant	-0.037	0.06	0.00	0.00	0.00	0.00	0.00	0.00	-0.04***	-0.03***	-0.01**	-0.00***	0.00***	0.00*	-0.00***	-0.00***	0.00***	-0.00***	-0.00***
	(0.191)	(0.09)	(0.00)	(0.00)	(0.00)	(0.03)	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	217	433	406	459	433	433	433	433	440	440	440	440	540	570	570	570	570	625	632
Number of countries	28	42	33	44	42	42	42	42	45	45	45	45	46	46	46	46	46	48	49

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. For the 'RAI indicator' model, the index for regional government policy or tax authority (Hooghe et al. 2016) is used as indicator of fiscal decentralization. The 'RAI Indicator' and the 'fixed effects' estimates are obtained using the fixed effects estimator. In all other cases, coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments.

Table B5. Robustness Check: Expenditure Decentralization; Dependent Variable: Public Spending on Applied R&D

Independent Variables	RAI indicator	Fixed Effects	GDP per capita>10k	Static model	Alternative Specifications of the main model (system GMM)														
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep. Var.$_{(t-1)}$	0.569***	0.63***	0.48***		0.39***	0.41***	0.50***	0.54***	0.57***	0.59***	0.64***	0.65***	0.62***	0.65***	0.68***	0.92***	0.87***	1.02***	1.05***
	(0.074)	(0.04)	(0.08)		(0.06)	(0.06)	(0.03)	(0.02)	(0.03)	(0.02)	(0.02)	(0.01)	(0.10)	(0.06)	(0.05)	(0.02)	(0.01)	(0.02)	(0.04)
Fiscal decentralization		0.00	-0.02***	-0.01***	-0.02***	-0.01**	-0.03***	-0.03***	-0.02***	-0.02***	-0.01***	-0.02***	-0.01***	-0.01***	-0.01***	0.00	0.00	-0.00	-0.00
		(0.01)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Decentralization imbalance		-0.01	0.02***	0.02***	0.01***	0.01*	0.03***	0.02***	0.02***	0.01***	0.01***	0.01***	0.01***	0.00	0.01***	-0.01***	-0.01**	0.00***	0.00
		(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Trade*high-tech. exports	-0.000	0.00	-0.00***	-0.00***	-0.00**	-0.00*	-0.00**	-0.00***	0.00*	0.00	0.00***	0.00***	-0.00	0.00	0.00	0.00***	0.00***	0.00	
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
Party orientation: left wing	-0.001	-0.00	0.00	0.00***	0.00	0.00	-0.00	-0.00	0.00***	0.00***	0.00***	0.00***	-0.00***	-0.00	0.00***	-0.00	0.00		
	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Party orientation: right	-0.001	-0.00	0.00	0.00***	-0.00*	0.00	-0.00***	-0.00***	0.00	0.00***	0.00***	0.00***	-0.00*	-0.00	0.00*	-0.00***	-0.00		
wing	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Urban pop.	-0.000	-0.00**	0.00***	-0.00***	0.00	-0.00**	0.00***	0.00**	0.00***	0.00*	0.00	0.00**	0.00**	0.00***	0.00***	-0.00			
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
Land area	0.000	-0.00	0.00***	0.00	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***				
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
Pol. system: presidential			-0.04***	-0.01**	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00**	-0.00	-0.00*	-0.00*	-0.00***					
			(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Pol. System: parliamentary	0.000	0.00	-0.00	-0.00*	-0.00	-0.00	-0.00**	-0.00	-0.00***	-0.00***	-0.00	-0.00	-0.00	-0.00**					
	(0.004)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Patent app. per capita	0.399	-0.81	1.90	11.71***	-2.74	-6.46***	-2.07	-0.45	1.15	-2.97**	-1.60	-0.04	1.47						
	(4.423)	(2.35)	(2.84)	(1.61)	(2.71)	(2.31)	(1.50)	(1.44)	(0.80)	(1.17)	(1.12)	(1.04)	(1.20)						
Unemployment	-0.000	0.00	0.00	-0.00	-0.00	-0.00**	0.00	0.00	-0.00***	-0.00***	-0.00***	-0.00***							
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
GDP (ll)	0.011	-0.01	0.00	0.00***	-0.00	-0.01**	-0.00	0.00***	0.00***	0.00***	0.00								
	(0.016)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)								
Internet access	0.000	0.00	-0.00	0.00***	0.00	0.00	0.00	0.00*	-0.00***	-0.00***									
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
Labor force (ll)	-0.012	0.00	0.00	0.00	0.00	0.01***	0.00	-0.01***	-0.00***										
	(0.011)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)										
Education index	-0.004	0.01	-0.01	0.00	-0.02*	-0.02*	-0.03***	-0.03***											
	(0.012)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)											
GDP per capita (ll)	-0.007	0.01	0.00	0.00	0.00**	0.01***	0.01***												
	(0.014)	(0.01)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)												
Population density	0.000	0.00	-0.00	0.00***	0.00	0.00***													
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
Gov. expenditure as % of	-0.000	-0.00***	-0.00	0.00***	0.00														
GDP	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)														
EU country dummy			0.00	-0.01***															
			(0.00)	(0.00)															
Regional government	0.001																		
policy authority	(0.002)																		
Constant	-0.093	0.08	0.00	0.00	-0.02	-0.04***	-0.03**	-0.01	-0.02***	-0.03***	-0.00	0.00***	0.00	0.00	-0.00***	0.00***	0.00***	-0.00*	-0.00
	(0.261)	(0.13)	(0.00)	(0.00)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	217	433	406	459	433	433	433	433	440	440	440	440	540	570	570	570	570	625	632
Number of countries	28	42	33	44	42	42	42	42	45	45	45	45	46	46	46	46	46	48	49

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. For the 'RAI indicator' model, the index for regional government policy or tax authority (Hooghe et al. 2016) is used as indicator of fiscal decentralization. The 'RAI Indicator' and the 'fixed effects' estimates are obtained using the fixed effects estimator. In all other cases, coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments.

Table B6. Robustness Check: Expenditure Decentralization; Dependent Variable: Total Public R&D Spending

Independent Variables	RAI indicator	Fixed Effects	GDP per capita>10k	Static model	Alternative Specifications of the main model (system GMM)														
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep. Var.$_{(t-1)}$	0.453***	0.57***	0.65***		0.52***	0.56***	0.60***	0.53***	0.62***	0.73***	0.72***	0.67***	0.63***	0.82***	0.73***	0.88***	0.87***	1.01***	0.94***
	(0.076)	(0.04)	(0.06)		(0.03)	(0.04)	(0.09)	(0.07)	(0.04)	(0.02)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)
Fiscal decentralization		-0.02**	-0.03***	0.01	-0.02**	-0.02***	-0.01	-0.01*	-0.01**	-0.01***	-0.01**	-0.01**	-0.00	-0.00	-0.01***	-0.01**	-0.00	-0.00**	-0.00***
		(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Decentralization imbalance		0.02	0.04***	-0.02	0.02***	0.02***	0.02***	0.01***	0.02***	0.02***	0.02***	0.01***	0.01***	0.01***	0.02***	0.01**	0.00	0.01***	0.01***
		(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Trade*high-tech. exports	-0.000	0.00	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00*	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	0.00***	-0.00	0.00	
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
Party orientation: left wing	-0.000	-0.00	0.00	0.00*	-0.00*	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	0.00	-0.00*		
	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Party orientation: right	-0.001	-0.00*	0.00	-0.00	-0.00	-0.00	-0.00**	-0.00**	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00	0.00***	0.00		
wing	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Urban pop.	-0.000	-0.00***	0.00***	0.00**	0.00	-0.00	0.00	0.00*	-0.00	0.00***	0.00**	0.00**	0.00*	0.00	0.00***	0.00***			
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
Land area	0.000	-0.00	0.00***	-0.00	0.00***	0.00***	0.00***	0.00*	0.00*	-0.00	0.00	0.00	0.00***	0.00*	-0.00				
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
Pol. system: presidential			-0.01	-0.01***	-0.00	-0.01***	-0.00	0.00	0.00	0.00	-0.00*	-0.00*	-0.01***	-0.01***					
			(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Pol. System: parliamentary	0.001	-0.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	-0.00	0.00***	0.00***	0.00***	0.00	-0.00					
	(0.004)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Patent app. per capita	-1.063	0.36	-2.11	1.03	-1.28	1.03	-3.71	-1.18	1.97	-4.42	-4.87***	-3.09	0.08						
	(4.836)	(2.70)	(4.77)	(3.39)	(3.10)	(2.28)	(3.16)	(3.50)	(3.09)	(2.74)	(1.58)	(2.31)	(1.79)						
Unemployment	0.000**	0.00*	-0.00***	-0.00**	0.00	-0.00	-0.00	0.00	0.00	-0.00***	-0.00***	-0.00***							
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
GDP (ll)	0.023	-0.00	-0.00***	-0.00**	-0.00***	-0.00***	0.01	0.01***	0.00	0.00**	-0.00								
	(0.017)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)								
Internet access	-0.000	-0.00***	-0.00***	-0.00***	-0.00***	-0.00	-0.00**	-0.00	-0.00	-0.00***									
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
Labor force (ll)	-0.013	-0.00	0.00	0.00	0.00	0.00	-0.01	-0.01**	-0.00**										
	(0.012)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)										
Education index	-0.005	0.01	0.00	0.03**	-0.00	-0.00	0.02	-0.00											
	(0.013)	(0.01)	(0.00)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)											
GDP per capita (ll)	-0.014	0.00	0.00	0.01	0.01***	0.00***	-0.01												
	(0.015)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)												
Population density	-0.000	0.00**	-0.00***	-0.00***	-0.00**	-0.00													
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
Gov. expenditure as % of	-0.000**	-0.00***	0.00	0.00	-0.00														
GDP	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)														
EU country dummy			0.02***	-0.01*															
			(0.01)	(0.00)															
Regional government	-0.006**																		
policy authority	(0.003)																		
Constant	-0.223	0.20	0.00	0.00	0.00	0.00	-0.03	-0.02	0.02	-0.02**	0.01	0.00	0.00	0.00*	-0.01***	-0.00	0.00***	-0.00	0.00**
	(0.288)	(0.15)	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.02)	(0.03)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	217	433	406	459	433	433	433	433	440	440	440	440	540	570	570	570	570	625	632
Number of countries	28	42	33	44	42	42	42	42	45	45	45	45	46	46	46	46	46	48	49

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. For the 'RAI indicator' model, the index for regional government policy or tax authority (Hooghe et al. 2016) is used as indicator of fiscal decentralization. The 'RAI Indicator' and the 'fixed effects' estimates are obtained using the fixed effects estimator. In all other cases, coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments.

Table B7. Robustness Check: Expenditure Decentralization; Dependent Variable: Share of Basic Research in Public R&D

Independent Variables	RAI indicator	Fixed Effects	GDP per capita>10k	Static model	Alternative Specifications of the main model (system GMM)														
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep. Var.$_{(t-1)}$	0.684***	0.78***	0.80***		0.76***	0.75***	0.94***	0.97***	0.94***	0.94***	0.98***	0.94***	0.86***	0.90***	0.90***	0.87***	0.88***	0.94***	0.85***
	(0.069)	(0.04)	(0.02)		(0.08)	(0.09)	(0.05)	(0.05)	(0.04)	(0.05)	(0.05)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)	(0.02)	(0.03)
Fiscal decentralization		-0.51	-1.22***	-0.32	-0.76**	-0.41	-0.77***	-0.75***	-0.70***	-0.76***	-0.51***	-0.24**	0.20	-0.09	-0.07	-0.98***	-1.00***	0.08***	0.23***
		(0.45)	(0.22)	(1.10)	(0.31)	(0.51)	(0.27)	(0.26)	(0.24)	(0.25)	(0.17)	(0.12)	(0.17)	(0.18)	(0.14)	(0.31)	(0.22)	(0.03)	(0.05)
Decentralization imbalance		0.66	1.53***	-0.26	1.11**	0.82	1.18***	1.07***	1.00***	1.02***	0.78***	0.53**	0.15	0.65**	0.75***	1.87***	1.70***	-0.04	0.08
		(0.46)	(0.18)	(1.23)	(0.46)	(0.65)	(0.42)	(0.35)	(0.34)	(0.29)	(0.25)	(0.22)	(0.22)	(0.29)	(0.17)	(0.39)	(0.30)	(0.09)	(0.08)
Trade*high-tech. exports	-0.000	-0.00	-0.00*	0.00	-0.00	-0.00**	0.00	-0.00	0.00	0.00	-0.00	-0.00**	-0.00	-0.00	-0.00	-0.00***	-0.00***	-0.00	
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
Party orientation: left wing	0.028	0.01	-0.04*	-0.08	-0.02*	-0.01	-0.00	-0.00	0.00	-0.01	0.01	0.00	-0.00	-0.01	-0.01	0.00	-0.02		
	(0.034)	(0.02)	(0.02)	(0.06)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)		
Party orientation: right	0.021	0.00	-0.01	-0.06	0.00	-0.04*	-0.03	-0.02	-0.02	-0.02	-0.01	-0.00	-0.01	-0.01	0.01	0.02	-0.00		
wing	(0.033)	(0.02)	(0.03)	(0.09)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.01)		
Urban pop.	0.006	0.00	0.00	0.02	0.01**	0.00	0.00	0.00	0.00	0.01**	-0.00	-0.00	0.00	0.00*	0.00**	0.00			
	(0.009)	(0.01)	(0.00)	(0.02)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
Land area	-0.000	0.00	-0.00	0.00	-0.00	-0.00***	-0.00	-0.00	-0.00	-0.00	0.00	0.00	-0.00	-0.00	-0.00				
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
Pol. system: presidential			-0.60	0.54	0.21	0.59**	0.49**	0.36**	0.35***	0.27**	0.11	-0.03	0.18***	0.15*					
			(0.41)	(0.35)	(0.20)	(0.23)	(0.20)	(0.16)	(0.08)	(0.13)	(0.14)	(0.10)	(0.06)	(0.08)					
Pol. System: parliamentary	-0.043	-0.05	0.16	0.14	0.00	0.02	0.15	0.09	0.19*	0.19*	0.17	0.11	0.20***	0.18***					
	(0.200)	(0.07)	(0.12)	(0.39)	(0.09)	(0.10)	(0.09)	(0.09)	(0.10)	(0.10)	(0.11)	(0.09)	(0.07)	(0.05)					
Patent app. per capita	44.233	79.08	214.68	-400.06	149.30	233.46*	-63.21	-10.10	-12.81	-90.40*	-56.33	-38.76	-132.39**						
	(241.256)	(124.89)	(161.85)	(323.87)	(118.07)	(141.05)	(84.59)	(73.80)	(78.64)	(48.28)	(48.61)	(35.96)	(53.19)						
Unemployment	0.006	0.00	0.01*	0.00	0.01***	0.01***	0.01***	0.01***	0.01***	0.00***	0.00*	0.00**							
	(0.005)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
GDP (ll)	-0.004	-0.11	-0.00	-0.43	0.14	0.97**	-0.21	0.12**	0.09***	0.04**	0.04***								
	(0.877)	(0.37)	(0.01)	(0.82)	(0.29)	(0.44)	(0.27)	(0.06)	(0.04)	(0.02)	(0.01)								
Internet access	-0.001	-0.00*	-0.00	-0.00	-0.00***	-0.00	-0.00***	-0.00*	-0.00***	-0.00**									
	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
Labor force (ll)	0.270	0.17	0.00	0.59	-0.20	-1.12**	0.21	-0.14**	-0.09*										
	(0.597)	(0.31)	(0.00)	(0.88)	(0.32)	(0.48)	(0.28)	(0.07)	(0.05)										
Education index	0.147	-0.20	0.00	-1.16	0.15	0.37	0.30	0.16											
	(0.638)	(0.37)	(0.00)	(1.40)	(0.33)	(0.40)	(0.39)	(0.28)											
GDP per capita (ll)	-0.086	0.08	0.00	0.51	-0.04	-0.75*	0.29												
	(0.768)	(0.33)	(0.00)	(0.82)	(0.24)	(0.40)	(0.24)												
Population density	0.000	-0.00	-0.00***	-0.00**	-0.00**	-0.00**													
	(0.004)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
Gov. expenditure as % of	-0.004	0.00	-0.00*	-0.01	-0.00														
GDP	(0.003)	(0.00)	(0.00)	(0.00)	(0.00)														
EU country dummy			0.05	1.04***															
			(0.18)	(0.29)															
Regional government	-0.076																		
policy authority	(0.120)																		
Constant	4.745	-1.77	0.00	-3.06	-0.76	-1.07	-1.03*	-1.30***	-1.50***	-1.38***	-1.04***	-0.02	-0.18	-0.30***	-0.13**	-0.07	0.10***	0.00	-0.01
	(14.192)	(6.68)	(0.00)	(2.52)	(0.63)	(0.66)	(0.56)	(0.48)	(0.24)	(0.47)	(0.39)	(0.14)	(0.11)	(0.10)	(0.05)	(0.12)	(0.03)	(0.01)	(0.02)
Observations	217	429	405	459	429	429	429	429	436	436	436	436	536	566	566	566	566	620	626
Number of countries	28	41	33	44	41	41	41	41	44	44	44	44	45	45	45	45	45	47	48

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. For the 'RAI indicator' model, the index for regional government policy or tax authority (Hooghe et al. 2016) is used as indicator of fiscal decentralization. The 'RAI Indicator' and the 'fixed effects' estimates are obtained using the fixed effects estimator. In all other cases, coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments.

Table B8. Robustness Check: Revenue Decentralization; Dependent Variable: Public Spending on Basic R&D

Independent Variables	RAI indicator (1)	Fixed Effects (2)	GDP per capita>10k (3)	Static model (4)	Alternative Specifications of the main model (system GMM) (5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep. Var.$_{(t-1)}$	0.647***	0.72***	0.96***		0.87***	0.88***	0.88***	0.88***	0.88***	0.95***	0.97***	0.96***	0.93***	0.93***	0.97***	0.95***	0.94***	0.98***	0.95***
	(0.076)	(0.03)	(0.05)		(0.03)	(0.04)	(0.02)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)
Fiscal decentralization		-0.02***	-0.02***	0.01***	-0.01***	-0.02***	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***	-0.01***	-0.00*	-0.00**	0.00***
		(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Decentralization imbalance		0.00	0.01***	-0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.01***	0.00***	0.00***	0.01***	0.01***	0.00***	0.00***	0.01***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Trade*high-tech. exports	-0.000	0.00	-0.00	-0.00	-0.00***	-0.00**	0.00	-0.00	-0.00***	-0.00	-0.00	-0.00***	-0.00	-0.00**	-0.00**	-0.00***	-0.00***	0.00***	
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
Party orientation: left wing	0.000	-0.00	-0.00	0.00***	-0.00*	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00*	0.00***		
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Party orientation: right wing	0.000	-0.00	-0.00	-0.00***	-0.00*	-0.00*	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	0.00***	0.00***	0.00***		
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Urban pop.	0.000	-0.00**	0.00	0.00***	-0.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	0.00	-0.00***	-0.00***	0.00***	0.00***			
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
Land area	-0.000	-0.00	-0.00	-0.00	0.00***	0.00***	0.00	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***				
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
Pol. system: presidential			-0.00	0.00	0.00***	0.00	0.01***	0.01***	0.00***	-0.00	0.00**	-0.00	-0.00***	-0.00***					
			(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Pol. System: parliamentary	-0.001	-0.00	0.00*	0.01***	0.00	0.00	0.00***	0.00*	0.00***	0.00***	0.00***	0.00***	0.00	0.00***					
	(0.003)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Patent app. per capita	-2.026	0.78	-1.68	4.79**	-1.13	0.73	1.12	1.62*	1.16**	1.13**	-0.12	1.69***	1.17***						
	(3.211)	(1.74)	(2.32)	(1.98)	(1.24)	(1.60)	(1.14)	(0.86)	(0.54)	(0.49)	(0.60)	(0.54)	(0.37)						
Unemployment	0.000***	0.00*	0.00**	-0.00	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***							
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
GDP (ll)	0.013	0.00	0.00	-0.00	-0.00***	0.00	-0.01**	0.00***	0.00***	-0.00**	0.00**								
	(0.012)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)								
Internet access	-0.000	-0.00***	-0.00	-0.00**	0.00***	0.00*	-0.00***	-0.00**	-0.00***	-0.00***									
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
Labor force (ll)	-0.006	-0.00	0.00	0.00	0.00	-0.00	0.01**	-0.00***	-0.00***										
	(0.008)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)										
Education index	0.005	0.00	-0.00	-0.01	-0.02***	-0.02***	-0.01	-0.00											
	(0.008)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)											
GDP per capita (ll)	-0.010	-0.00	0.00	0.00	0.01***	0.00	0.01***												
	(0.010)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)												
Population density	0.000	0.00	-0.00	-0.00***	-0.00*	-0.00													
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
Gov. expenditure as % of GDP	-0.000***	-0.00	-0.00	-0.00**	0.00														
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)														
EU country dummy			-0.00	-0.00															
			(0.00)	(0.00)															
Regional government tax authority	-0.001**																		
	(0.001)																		
Constant	-0.055	0.06	0.00	0.01	0.00	-0.03	-0.02*	-0.04***	-0.03***	0.00	-0.01***	-0.00***	0.00***	0.00*	-0.00***	-0.00***	0.00	-0.00***	-0.00***
	(0.196)	(0.09)	(0.00)	(0.03)	(0.00)	(0.02)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	217	433	406	459	433	433	433	433	440	440	440	440	540	570	570	570	570	625	632
Number of countries	28	42	33	44	42	42	42	42	45	45	45	45	46	46	46	46	46	48	49

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. For the 'RAI indicator' model, the index for regional government policy or tax authority (Hooghe et al. 2016) is used as indicator of fiscal decentralization. The 'RAI Indicator' and the 'fixed effects' estimates are obtained using the fixed effects estimator. In all other cases, coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments.

Table B9. Robustness Check: Revenue Decentralization; Dependent Variable: Public Spending on Applied R&D

Independent Variables	RAI indicator (1)	Fixed Effects (2)	GDP per capita>10k (3)	Static model (4)	Alternative Specifications of the main model (system GMM) (5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep. Var.$_{(t-1)}$	0.572***	0.63***	0.55***		0.35***	0.51***	0.58***	0.61***	0.53***	0.56***	0.60***	0.66***	0.69***	0.68***	0.71***	0.95***	0.85***	1.01***	0.95***
	(0.074)	(0.04)	(0.07)		(0.05)	(0.06)	(0.05)	(0.05)	(0.04)	(0.02)	(0.02)	(0.02)	(0.08)	(0.06)	(0.05)	(0.01)	(0.02)	(0.02)	(0.02)
Fiscal decentralization		0.00	-0.01*	-0.02**	-0.00	-0.01***	-0.02***	-0.02***	-0.02***	-0.02***	-0.02***	-0.01***	-0.01**	-0.01***	-0.01***	0.00	0.00	-0.00	-0.00
		(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Decentralization imbalance		-0.01	0.01*	0.00	-0.00	0.00	-0.00	-0.00	-0.01***	-0.01***	-0.01***	-0.01***	-0.00*	-0.01***	-0.01***	-0.01***	-0.01***	0.00***	0.00***
		(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Trade*high-tech. exports	-0.000	0.00	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	0.00	0.00***	0.00***	0.00***	0.00	0.00*	0.00	0.00***	0.00***	-0.00	
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
Party orientation: left wing	-0.001	-0.00	0.00	0.00***	0.00	0.00***	-0.00	0.00	0.00***	0.00***	0.00***	0.00***	-0.00***	-0.00**	0.00***	0.00**	0.00***		
	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Party orientation: right	-0.001	-0.00	0.00	0.00***	0.00	0.00***	-0.00***	-0.00***	-0.00***	-0.00	-0.00	0.00	-0.00***	-0.00**	0.00	0.00	0.00		
wing	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Urban pop.	-0.000	-0.00**	-0.00	-0.00*	-0.00**	-0.00	0.00	0.00*	0.00*	0.00***	0.00	0.00**	0.00***	0.00***	0.00***	-0.00**			
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
Land area	0.000	-0.00	0.00***	-0.00	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***	0.00**	0.00***	0.00***				
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
Pol. system: presidential			-0.01	-0.01**	-0.00	-0.01*	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00*					
			(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Pol. System: parliamentary	0.000	0.00	0.00	-0.00***	-0.00**	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00					
	(0.004)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Patent app. per capita	0.603	-0.81	-2.15	1.83	-0.28	-2.12	0.27	0.22	-2.43**	-3.01***	-4.02***	-1.22	-0.11						
	(4.412)	(2.35)	(5.05)	(4.31)	(2.06)	(2.72)	(1.98)	(0.96)	(1.18)	(1.03)	(1.21)	(1.10)	(1.30)						
Unemployment	-0.000	0.00	0.00	-0.00	-0.00	-0.00**	0.00	-0.00	-0.00**	-0.00***	-0.00***	-0.00***							
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
GDP (ll)	0.010	-0.01	-0.00	-0.01*	0.00***	0.00***	0.00	0.00***	0.00***	0.00***	0.00***								
	(0.016)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)								
Internet access	0.000	0.00	-0.00	-0.00*	0.00	-0.00**	0.00	0.00	-0.00***	-0.00***									
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
Labor force (ll)	-0.011	0.00	0.00	0.01*	0.00	0.00	-0.01	-0.00***	-0.00										
	(0.011)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)										
Education index	-0.006	0.01	0.01	0.02*	0.00	0.01	-0.02**	-0.02***											
	(0.012)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)											
GDP per capita (ll)	-0.006	0.01	0.00	0.02*	0.00	0.00	0.00												
	(0.014)	(0.01)	(0.00)	(0.01)	(0.00)	(0.00)	(0.01)												
Population density	0.000	0.00	-0.00	0.00**	0.00***	0.00**													
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
Gov. expenditure as % of	-0.000	-0.00***	-0.00	0.00	-0.00*														
GDP	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)														
EU country dummy			0.00	-0.01***															
			(0.01)	(0.00)															
Regional government tax	0.000																		
authority	(0.001)																		
Constant	-0.094	0.08	0.00	0.03	0.00	-0.03***	0.00	0.00	-0.03***	-0.03***	-0.02***	0.00**	0.00	0.00	-0.00**	0.00***	0.00***	-0.00	-0.00
	(0.262)	(0.13)	(0.00)	(0.04)	(0.00)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	217	433	406	459	433	433	433	433	440	440	440	440	540	570	570	570	570	625	632
Number of countries	28	42	33	44	42	42	42	42	45	45	45	45	46	46	46	46	46	48	49

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. For the 'RAI indicator' model, the index for regional government policy or tax authority (Hooghe et al. 2016) is used as indicator of fiscal decentralization. The 'RAI Indicator' and the 'fixed effects' estimates are obtained using the fixed effects estimator. In all other cases, coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments.

Table B10. Robustness Check: Revenue Decentralization; Dependent Variable: Total Public R&D Spending

Independent Variables	RAI indicator	Fixed Effects	GDP per capita>10k	Static model	Alternative Specifications of the main model (system GMM)														
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep. Var.$_{(t-1)}$	0.439***	0.57***	0.58***		0.51***	0.57***	0.59***	0.66***	0.61***	0.71***	0.75***	0.74***	0.74***	0.80***	0.70***	0.90***	0.84***	0.97***	0.92***
	(0.077)	(0.04)	(0.07)		(0.05)	(0.04)	(0.05)	(0.05)	(0.06)	(0.03)	(0.01)	(0.02)	(0.04)	(0.03)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Fiscal decentralization		-0.02**	-0.01**	-0.00	-0.02***	-0.01	-0.01**	-0.01***	-0.02***	-0.01***	-0.01	-0.00	-0.01***	-0.00**	-0.00*	-0.01***	-0.01***	-0.00***	0.00**
		(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Decentralization imbalance		-0.00	0.01***	-0.01**	0.01	0.01***	0.00	0.00	0.00	0.01***	0.01***	0.01***	0.00	0.00	0.01***	0.00***	0.00***	0.00***	0.01***
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Trade*high-tech. exports	-0.000	0.00	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00**	-0.00***	-0.00*	-0.00*	-0.00**	-0.00***	-0.00	-0.00***	0.00***	0.00	0.00*	
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
Party orientation: left wing	-0.000	-0.00	-0.00	0.00	-0.00	-0.00*	-0.00***	-0.00***	-0.00***	-0.00***	-0.00	0.00**	-0.00***	-0.00***	-0.00	0.00***	0.00		
	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Party orientation: right wing	-0.001	-0.00*	0.00	0.00	-0.00	-0.00	-0.00***	-0.00***	-0.00**	-0.00**	-0.00	-0.00*	-0.00***	-0.00***	-0.00**	0.00	0.00		
	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)		
Urban pop.	-0.000	-0.00***	0.00	0.00	0.00***	0.00	0.00***	0.00	0.00***	0.00***	-0.00	0.00***	0.00	0.00	0.00***	0.00			
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
Land area	0.000	-0.00	0.00***	-0.00	0.00	0.00*	0.00	0.00**	0.00**	0.00**	0.00**	0.00**	0.00***	0.00*	-0.00				
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
Pol. system: presidential			-0.00	-0.01**	0.00	0.00	0.00	0.00	0.00	-0.00*	-0.00	-0.00	-0.01***	-0.01***					
			(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Pol. System: parliamentary	0.000	-0.00	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00**	0.00***	0.00	-0.00					
	(0.004)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)					
Patent app. per capita	-1.948	0.36	0.03	-6.27	-2.72	-5.47*	-4.39*	-2.89	-4.05*	-7.02***	-6.84**	-3.91**	-1.12						
	(4.818)	(2.70)	(4.24)	(4.52)	(4.40)	(3.25)	(2.66)	(2.88)	(2.37)	(2.14)	(3.00)	(1.58)	(1.84)						
Unemployment	0.000**	0.00*	0.00	-0.00**	-0.00	0.00*	-0.00	-0.00	-0.00	-0.00*	-0.00***	-0.00**							
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
GDP (ll)	0.027	-0.00	0.01***	-0.00***	0.00	0.01***	-0.00	0.00***	0.00**	0.00***	0.00*								
	(0.017)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)								
Internet access	-0.000	-0.00***	-0.00	-0.00***	-0.00***	-0.00**	-0.00***	-0.00**	-0.00***	-0.00***									
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
Labor force (ll)	-0.015	-0.00	-0.01***	0.00	0.00	-0.01***	0.00	-0.00**	-0.01**										
	(0.012)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)										
Education index	-0.002	0.01	-0.00	0.04**	-0.00	-0.00	0.01	0.00											
	(0.013)	(0.01)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)											
GDP per capita (ll)	-0.017	0.00	0.00	0.01***	0.01**	0.00	0.00*												
	(0.015)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)												
Population density	-0.000	0.00**	-0.00***	-0.00***	-0.00	-0.00													
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
Gov. expenditure as % of GDP	-0.000**	-0.00***	-0.00	0.00**	0.00*														
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)														
EU country dummy			0.02***	-0.01**															
			(0.01)	(0.00)															
Regional government tax authority	-0.002**																		
	(0.001)																		
Constant	-0.282	0.20	0.00	0.00	-0.08**	-0.06**	-0.05**	-0.05**	-0.05*	-0.06***	-0.02*	-0.00**	0.00*	0.00	-0.01***	0.00	0.00***	0.00*	-0.00
	(0.291)	(0.15)	(0.00)	(0.00)	(0.04)	(0.03)	(0.02)	(0.03)	(0.03)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Observations	217	433	406	459	433	433	433	433	440	440	440	440	540	570	570	570	570	625	632
Number of countries	28	42	33	44	42	42	42	42	45	45	45	45	46	46	46	46	46	48	49

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. For the 'RAI indicator' model, the index for regional government policy or tax authority (Hooghe et al. 2016) is used as indicator of fiscal decentralization. The 'RAI Indicator' and the 'fixed effects' estimates are obtained using the fixed effects estimator. In all other cases, coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments.

Table B11. Robustness Check: Revenue Decentralization; Dependent Variable: Share of Basic Research in Public R&D

Independent Variables	RAI indicator	Fixed Effects	GDP per capita>10k	Static model	Alternative Specifications of the main model (system GMM)														
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep. Var.$_{(t-1)}$	0.688***	0.78***	0.78***		0.68***	0.83***	0.98***	0.94***	0.94***	0.93***	0.96***	0.94***	0.86***	0.90***	0.90***	0.91***	0.91***	0.91***	0.73***
	(0.069)	(0.04)	(0.03)		(0.08)	(0.07)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.03)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)
Fiscal decentralization		-0.51	-1.02***	0.05	-0.93**	-1.38***	-0.84***	-0.93***	-0.80***	-0.61***	-0.53***	-0.29**	0.21	0.07	-0.01	-0.73***	-0.75***	0.16***	0.39***
		(0.45)	(0.21)	(0.65)	(0.42)	(0.30)	(0.21)	(0.21)	(0.19)	(0.14)	(0.14)	(0.14)	(0.20)	(0.19)	(0.13)	(0.15)	(0.16)	(0.04)	(0.06)
Decentralization imbalance		0.15	0.78***	-0.14	0.51*	0.61***	0.17	0.38***	0.44***	0.31***	0.22	0.29**	0.61***	0.76***	0.60***	0.71***	0.49***	0.48***	0.57***
		(0.22)	(0.17)	(0.39)	(0.27)	(0.17)	(0.17)	(0.15)	(0.16)	(0.12)	(0.14)	(0.12)	(0.12)	(0.14)	(0.16)	(0.11)	(0.11)	(0.11)	(0.11)
Trade*high-tech. exports	-0.000	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00	0.00	-0.00	-0.00	-0.00*	-0.00	-0.00**	-0.00***	-0.00***	
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	
Party orientation: left wing	0.029	0.01	0.02	-0.13***	-0.03*	-0.01	-0.01	-0.02	-0.01	-0.02	0.00	0.00	-0.01	-0.02*	-0.03**	0.01	-0.00		
	(0.034)	(0.02)	(0.03)	(0.05)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)		
Party orientation: right	0.023	0.00	0.02	-0.11*	-0.01	-0.03**	-0.04**	-0.03*	-0.03*	-0.03**	-0.01	0.00	-0.02	-0.03***	-0.03**	0.01	0.01		
wing	(0.033)	(0.02)	(0.04)	(0.06)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)		
Urban pop.	0.006	0.00	0.00	0.02**	0.01**	0.01**	0.00**	0.00	0.00	0.00*	-0.00	-0.00	0.00	0.00**	0.00**	0.00**			
	(0.009)	(0.01)	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)			
Land area	-0.000	0.00	-0.00	0.00	-0.00**	-0.00**	-0.00	-0.00	-0.00	-0.00	0.00	0.00	-0.00	-0.00	-0.00				
	(0.000)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)				
Pol. system: presidential			-0.67**	0.21	0.44*	0.78***	0.36***	0.37***	0.41***	0.16	0.11	0.04	0.24***	0.17*					
			(0.32)	(0.22)	(0.24)	(0.20)	(0.12)	(0.08)	(0.07)	(0.11)	(0.11)	(0.10)	(0.08)	(0.10)					
Pol. System: parliamentary	-0.045	-0.05	0.02	0.24	0.08	0.23**	0.07	0.05	0.14*	0.16	0.17	0.16*	0.18**	0.15***					
	(0.200)	(0.07)	(0.09)	(0.20)	(0.12)	(0.09)	(0.08)	(0.06)	(0.08)	(0.11)	(0.11)	(0.09)	(0.08)	(0.05)					
Patent app. per capita	31.647	79.08	-83.78	-166.29	93.02	-63.28	2.79	-14.82	-13.19	-74.71*	21.79	-38.25	-215.54**						
	(240.576)	(124.89)	(141.10)	(265.57)	(85.86)	(96.69)	(58.70)	(58.19)	(69.52)	(42.28)	(48.37)	(38.28)	(92.17)						
Unemployment	0.006	0.00	0.01***	0.01	0.01***	0.01***	0.01***	0.01***	0.01***	0.00***	0.00**	0.00**							
	(0.005)	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)							
GDP (ll)	0.035	-0.11	0.00	0.43	0.26	-0.01	0.14	0.14***	0.15***	0.02*	0.03***								
	(0.876)	(0.37)	(0.00)	(0.60)	(0.28)	(0.26)	(0.14)	(0.04)	(0.03)	(0.01)	(0.01)								
Internet access	-0.001	-0.00*	0.00*	-0.00	-0.00***	-0.00***	-0.00***	-0.00***	-0.00***	-0.00**									
	(0.001)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)									
Labor force (ll)	0.226	0.17	0.00	-0.41	-0.34	0.03	-0.11	-0.12**	-0.18***										
	(0.593)	(0.31)	(0.00)	(0.68)	(0.29)	(0.27)	(0.14)	(0.05)	(0.05)										
Education index	0.230	-0.20	0.00	-0.33	-0.17	-0.10	0.18	-0.05											
	(0.626)	(0.37)	(0.00)	(0.96)	(0.34)	(0.22)	(0.33)	(0.29)											
GDP per capita (ll)	-0.135	0.08	0.00	-0.46	-0.10	0.18	-0.03												
	(0.764)	(0.33)	(0.00)	(0.63)	(0.26)	(0.23)	(0.14)												
Population density	0.000	-0.00	-0.00***	-0.00***	-0.00***	-0.00***													
	(0.004)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)													
Gov. expenditure as % of	-0.004	0.00	-0.00**	-0.01***	-0.00														
GDP	(0.003)	(0.00)	(0.00)	(0.00)	(0.00)														
EU country dummy			0.16	0.97***															
			(0.15)	(0.22)															
Regional government tax	-0.008																		
authority	(0.036)																		
Constant	4.874	-1.77	0.00	-1.32	-0.97	-2.45***	-2.13***	-2.14***	-1.64***	-0.94***	-0.93***	-0.06	-0.34***	-0.36***	-0.15**	-0.17**	0.07	-0.04***	-0.02
	(14.284)	(6.68)	(0.00)	(1.36)	(0.64)	(0.55)	(0.49)	(0.46)	(0.28)	(0.36)	(0.27)	(0.14)	(0.13)	(0.11)	(0.07)	(0.08)	(0.04)	(0.01)	(0.01)
Observations	217	429	405	459	429	429	429	429	436	436	436	436	536	566	566	566	566	620	626
Number of countries	28	41	33	44	41	41	41	41	44	44	44	44	45	45	45	45	45	47	48

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. For the 'RAI indicator' model, the index for regional government policy or tax authority (Hooghe et al. 2016) is used as indicator of fiscal decentralization. The 'RAI Indicator' and the 'fixed effects' estimates are obtained using the fixed effects estimator. In all other cases, coefficients and standard errors estimated through two-step system GMM, applying forward orthogonal deviations transformation. All independent variables were assumed to be endogenous, and year dummies were included as exogenous instruments.