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Daniel Gama e Colombo

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International Center for Public Policy
Andrew Young School of Policy Studies
Georgia State University
Atlanta, Georgia 30303
United States of America

Phone: (404) 413-0235
Fax: (404) 651-4449
Email: paulbenson@gsu.edu
Internet: http://icepp.gsu.edu/

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

Daniel Gama e Colombo* and Jorge Martinez-Vazquez**

Abstract

This paper examines the impact of fiscal decentralization on both public investment in innovation (measured as the share of research and development - R&D - spending in total government budget) and on the intensity of basic research within the public R&D bundle. We present a theoretical model where a 'benevolent government' invests in R&D aiming at maximizing net income available in the country (central government) or in the respective region (subnational government), where states compete to attract capital investment, and where 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 government R&D budget. The implications of the model are empirically tested utilizing country aggregate data. We find evidence that expenditure decentralization leads to lower intensity of basic research within public R&D, and that both revenue and expenditure decentralization negatively affect the size of innovation spending. The findings suggest that fiscal decentralization policy, expected to be beneficial in many other dimensions, should be accompanied by measures to compensate for the otherwise decrease in innovation spending, and that the assignment of expenditure responsibilities should have central government play a greater role in financing and carrying out basic research.

*National Institute of Educational Studies and Research Anísio Teixeira, Brazil

**International Center for Public Policy, Georgia State University, USA

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1 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 2008-2009 crisis (OECD, 2014). In this paper, we examine how these two policy trends interact, and, more specifically, what is the potential impact of fiscal decentralization on public spending on research and development (R&D).

The fiscal federalism literature (briefly reviewed in section 2) 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 & Schwab, 1997), factor mobility (Brennan & Buchanan, 1980) and state competition (Zodrow & 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 et al. (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 section 2, 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 spreads 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, fiscal competition may generate incentives for subnational governments to increase innovation spending to attract new capital investment (Keen & 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 there is any impact of fiscal decentralization on the share of R&D in the government budget; and (b) whether fiscal decentralization also affects 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 rest of the paper is structured as follows: in the second section we discuss the intersection of the economic literatures on fiscal decentralization and knowledge spillovers arising from R&D investments. The third section presents the theoretical model and derives the propositions to be tested empirically. In the fourth section we describe the data, perform the empirical analysis and discuss the results, along with potential policy implications. The final section concludes and suggests further research agenda on this subject.

2 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 arguments and evidence presented by the literatures on these topics.

2.1 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

[1] Throughout this paper, we use the standard definitions of innovation related concepts presented in the OECD Frascati Manual: innovation consists in the development of new information or increase in the stock of knowledge, and its application for economic purposes; 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).

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, as already mentioned, 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 & Välilä, 2008).

This requirement was later relaxed by studies that admitted a third type of public goods that, in spite of being consumed locally, generates interregional spillovers that influence the production or welfare of people residing elsewhere (Besley & Coate, 2003; Feidler & Staal, 2012; Hulten & Schwab, 1997; Oates, 2008a, 2008b; Ponce-Rodriguez, Hankla, Martinez-Vazquez, & Heredia-Ortiz, 2018). These externalities reduce the incentives of local governments to 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.

Four main approaches have been suggested to deal with interregional spillovers. The original analysis by Oates (1972, 2008b) merely acknowledges that there is a tradeoff between the welfare gains of decentralization and the inefficiency costs introduced by externalities, and calls for weighting these effects to decide whether a public good with these features is more efficiently provided by central or local governments. The second approach is the adoption of Pigouvian intergovernmental grants, designed to compensate subnational governments for their investments and therefore helping internalize the potential externalities (Oates, 1999, 2008a). The third one is a Coase type solution, in which subnational governments bargaining over externalities should reach an efficient solution for provision of a public good, assuming low transaction costs (Hulten & Schwab, 1997). Finally, a political system of centralized parties - which, unlike a decentralized party system, aim to national level objectives - can help correct the otherwise inefficient underprovision of public goods by local elected officials (Ponce-Rodriguez et al., 2018).

The problem of interregional spillovers becomes more complicated as one introduces factor mobility. A long strand of the literature has argued that households or capital can move to more privileged locations to take advantage of lower taxes or higher levels of public goods or infrastructure (Tiebout 1956). The 'Leviathan hypothesis' (Brennan & Buchanan, 1980) suggests that fiscal decentralization limits the tax power and government size because local governments have to compete for constituents and resources that are mobile. The erosion of

the tax base can also lead to an overall reduction of public services provision through a 'race to the bottom' (Zodrow & 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 & Schwab, 1997).

A different 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, & Sacchi, 2017). Part of these studies focused on the composition of government budget, although this is still a relatively new and underexplored topic (Jia, Guo, & 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. Busemeyer (2007) expands the forms of expenditure competition. Once we allow for mobility of households, subnational governments may compete to attract constituencies by raising their expenditure in education.

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, and Arze del Granado, Martinez-Vazquez, and McNab 2016). 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 et al., 2014; Kappeler & Välilä, 2008; Sacchi & Salotti, 2016), and for education or human capital (Ashworth, Galli, & Padovano, 2009; Busemeyer, 2007; Faguet, 2004; Arze del Granado et al., 2016; Kappeler & Välilä, 2008; Sacchi & Salotti, 2016), although at least in one case a negative impact on education was found (Jia et al., 2014). There is also evidence of positive impact on health (Arze del Granado et al., 2016; Kappeler & Välilä, 2008) and pork-barrel expenses (Diaz-Cayeros, McElwain, Romero, & Siewierski, 2002).

Some of the main expenditure categories that experience a reduction in their share of the government budget because of decentralization are welfare (Grisorio & Prota, 2015) and social security (Ashworth et al., 2009; Fiva, 2005), following the results of Keen and Marchand's (1997) model.

Considering the importance of interregional spillovers, one expects that they should play an important role in determining how decentralization affects the composition of the public budget. However, most analyses did not expressly consider the case of local goods with interjurisdictional spillovers. As one of the exceptions, Kappeler and Välilä (2008) concluded

that the impact of decentralization on these goods is ambiguous, depending on whether spillovers are dominantly local or global.

Finally, 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 analysis (Grisorio & Prota, 2015), but, even in this case, the authors did not include it in their econometric analysis.

2.2 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 (for recent reviews, see Edler et al., 2013; Edler and Fagerberg, 2017; 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 an inefficient underinvestment level in R&D by private agents, thus requiring additional public resources to supplement it (Arrow, 1962; Hall, Mairesse, & Mohnen, 2010; Köhler, Laredo, & 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 et al., 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; Romer, 1990). The non-appropriated knowledge can be used by different firms and individuals for production and future research. As suggested in Romer's (1990) model, the marginal product of R&D is higher than the return obtained by the R&D-investing firm, because it only captures part of the value of the innovation, not benefiting from the value of the externalities that are generated. As the firm does not profit from or appropriate such spillovers, it also 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 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 highest share of innovation outcomes, reaching up to twice the value of internalized results or more

(Bernstein & Nadiri, 1989; Bloom, Schankerman, & Van Reenen, 2013; Mansfield, Rapoport, Romeo, Wagner, & Beardsley, 1977).

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, as firms located in the same region or country where the technology is developed tend to benefit more from it. Peri (2005) estimated that no more than 20% of created knowledge goes outside the region of origin, and less than 9% leaves the country. There is also evidence that firms located close to academic centers are more likely to apply their research findings first (Mansfield & Lee, 1996), and that basic research cooperation decreases with distance (Katz, 1994). 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 & Feldman, 1996; Maurseth & Verspagen, 2002). But the strength of these factors may be temporary, as there is evidence suggesting that knowledge spillovers are only local in the short run, and that such geographic concentration fades over time (Jaffe, Trajtenberg, & Henderson, 1993).

Spillovers also positively affect productivity at the international level (Coe, Helpman, & Hoffmaister, 2009; Malerba, Mancusi, & Montobbio, 2013; Mancusi, 2008). Coe and Helpman (1995) concluded that about a quarter of total benefits of R&D in G7 countries spillovers to their trading partners. The magnitude of this result depends on the channels of transmission considered in the analysis, although the existence of substantial international knowledge externalities is generally unchallenged (Hall et al., 2010).

The geographic dispersal of knowledge spillovers can be influenced by different factors. A first one is the nature of innovative R&D. 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. Consequently, private firms should invest even less in this activity, calling for a greater role of public and non-profit organizations (U.S. JEC, 2010). Similar arguments have been suggested in other recent studies (Akcigit, Hanley, & Serrano-Velarde, 2013; Chu & Furukawa, 2013; Shapiro & Taylor, 2013). Schumpeterian growth models also considered that basic research yields more knowledge spillovers, and, for this reason, it is particularly important for economic growth (Aghion & Howitt, 1996). Empirical analyses confirmed that large spillovers arise from basic research (Salter & Martin, 2001): Funk (2002) found that it generates much larger international spillovers; Griliches

(1985), Mansfield (1980) and Lichtenberg and Siegel (1991) identified a "premium" for basic research, meaning that it is more important for productivity increase than other types of R&D; and Mansfield (1991) estimated a 28 percent social rate of return of academic research in the late 1970s.

A second factor to be considered when analyzing the spreading of knowledge spillovers is whether it arises from private or public research. Research on this distinction is still scarce, and the evidence related to public R&D is mostly focused on specific government research projects (Salter & Martin, 2001), but it suggests that the difference can be substantial. In an analysis of pharmaceutical research, Furman et al. (2006) noticed that locally generated knowledge is positively correlated with research productivity, provided that it comes from public R&D, and that the correlation becomes negative in the case of private research.

The literature review presented in this section suggests that there might be important links between the level of fiscal decentralization of a country and its public investment in innovation given the large associated spillovers, a topic that so far has not been explored by the economic literature. The model presented in the next section is a first attempt to fill this gap. Following the studies discussed herein, the main factors that explains the relation between these variables are the presence of knowledge spillovers with uneven geographic spreading, subnational government competition and the type of R&D (basic or applied) financed by the government.

3 Theoretical model: linking fiscal decentralization and public R&D

As the product of R&D activities, innovation presents typical features of public goods, i.e., non-rivalry and non-excludability (Arrow, 1962), and for this reason it is treated as such in different studies (Malerba et al., 2013; Verspagen, 1992; Verspagen & De Loo, 1999). A substantial share of its results constitutes positive externalities that are not internalized by the organizations incurring the respective production costs, and that partially flow to other firms across other subnational governments and countries. These features suggest that government investment in R&D activities can be considered a case of local public good with interjurisdictional spillovers, and therefore their production should be affected by the level of fiscal decentralization of a country.

Considering the concepts and arguments discussed in the previous section, we present here a simple model to explain how fiscal decentralization affects the share and composition of government expenditures in R&D, considering the broad categories of basic and applied

research (as defined below). Our objective is to model the detailed 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 & Coate, 2003; Dhillon, Wooders, & Zissimos, 2007; Zodrow & Mieszkowski, 1986). Following similar analysis (Besley & Coate, 2003; Dhillon et al., 2007; Feidler & Staal, 2012), the effects of decentralization are assessed by comparing the optimal decision of central and regional governments, both from the perspective of revenue (the power to collect taxes and determine applicable rates) and expenditure (composition of spending).

The formal specification of the model is based on two streams of literature: (a) fiscal decentralization models with interjurisdictional spillovers (Besley & Coate, 2003; Feidler & Staal, 2012; Arze del Granado et al., 2016; Oates & Schwab, 1988) and with public goods as inputs to production (Dhillon et al., 2007; Zodrow & Mieszkowski, 1986), which are used to design government incentives and decisions at the national and lower levels; and (b) Schumpeterian endogenous growth models (Aghion & Howitt, 1992, 1998) and their extensions to include basic research (Aghion & Howitt, 1996; Cozzi & Galli, 2009) and public R&D (Morales, 2004), which provide the description of the innovation process and its contribution to output.

3.1 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 & 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 & Schwab, 1988; Zodrow & 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 of each firm (A_{it}), 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. 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 1:

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

(1)

As Equation 1 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):

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

(2)

Both the central and regional public budgets (G_{it}) are balanced, so there is no public savings or deficit, 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:

$$G_{it} = k_{it} z_{it}$$

(3)

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 4. 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 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.

$$\Delta A_{it} = A_{it} - A_{i,t-1} = G_{it} f(b_{it}) + \sum_{J=1}^{n-1} G_{Jt} h(b_{Jt}) \quad ; \quad J \neq i \tag{4}$$

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, meaning that applied research is required to apply such knowledge to the production process (Auerswald, Branscomb, Demos, & Min, 2003; Morales, 2004). Investment in applied research, on the other hand, is a sufficient condition to improve technology, for it can be based on incremental or secondary innovation (Aghion & Howitt, 1998), but its productivity and results are improved by basic research knowledge. This description suggests the following functional form for the R&D productivity factor:[2]

$$f(b_{it}) = (1 - b_{it})\big(\theta(1 - s_A) + b_{it}\gamma(1 - s_B)\big) \tag{5}$$

Where $s_b > s_a$ (5a)

The positive parameter (θ) represents the productivity of applied research, (γ) is the contribution of basic research to productivity improvement, and (s_b) and (s_a) are the levels of interregional spillovers of basic and applied research, respectively. As suggested by the literature discussed in section 2, we assume that interjurisdictional spillovers represent a higher share of results in the case of basic research (Equation 5a). These 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 can be simplified as presented in Equation 6.

$$\sum_{J=1}^{n-1} G_{Jt} h(b_{Jt}) = \sum_{J=1}^{n-1} G_{Jt} \left(\left(\frac{1}{n-1}\right)(1 - b_{Jt})\left(\theta(s_A) + \gamma b_{Jt}(s_B)\right)\right) = \tag{6}$$

$$G_{jt}(1 - b_{jt})\big(\theta(s_A) + \gamma b_{it}(s_B)\big)$$

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

3.2 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 1. To achieve this goal, it taxes locally-invested capital and spends the public 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 number of communities, competition equalizes such rate among all jurisdictions (Zodrow & Mieszkowski, 1986), so firms and governments take it as given. Considering the relation between marginal product of capital, taxes and interest rates expressed in Equation 2, the exogenous interest rate determines the capital constraint of the regional government's maximization problem (Equation 8):

$$r_t = \bar{r}^R \tag{7}$$

$$\alpha \left(\frac{A_{it}}{k_{it}}\right)^{1-\alpha} - z_{it} = \bar{r}^R \tag{8}$$

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 4), they negatively impact the net income through two effects: (a) by reducing the available income (Equation 1); and (b) by reducing the marginal product of capital (Equation 2). The level of taxation is then chosen to maximize local net income according to Equation 1, subject to the budget and capital constraints in Equations 3 and 8, and the expected technology improvement in the province (Equation 4). Taking the first order conditions and solving the system of equations, we find the optimal tax rate of the regional government (z_i^{R*}).

$$\frac{\partial y_{it}^c}{\partial z_{it}} = 0 \rightarrow z_i^{R*} = \left((1-\alpha) f_i^{R*} \bar{r}^R\right)^{1-\alpha} \alpha^{\alpha} - \bar{r}^R \tag{9}$$

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

(9a)

The first term on the right side of equation 9 represents the optimal marginal product of capital, that is affected both by the technology level and the applicable interest rate. Equation 9 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. 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 4 with respect to the share of basic research (b_{it}).[3] The efficient share of basic research (b_i^{R*}) displayed in Equation 8 is positively correlated with its own contribution (γ), and negatively correlated with the applied research productivity parameter (θ). As expected, the influence of these parameters in the optimal composition rate is reduced by the respective interjurisdictional spillovers, as these results are not accounted for by regional governments in their decision.

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

(10)

3.3 The Central Government Decision

We now consider the optimal 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

[3] 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.

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.

$$y_t^C = \sum_{I=1}^{n}(k_{It}^{\alpha}A_{It}^{1-\alpha} - k_{It}(z_t + r_t) + (\overline{K}/n)r_t) = n(k_{it}^{\alpha}A_{it}^{1-\alpha} - k_{it}z_{it}) \quad ; \quad i \in I \quad (11)$$

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:

$$\bar{k} = \sum_{i=0}^{n} k_{it} \rightarrow k_{it} = \frac{\bar{k}}{n} \quad (12)$$

The second difference is the technology function. The central government considers interjurisdictional knowledge spillovers along with internal 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 externality loss (or gain) at the national level. This effect is represented by the sum of all regional outputs in Equation 11. A different way to understand this is to apply the national rates to the spillover and R&D productivity functions (Equations 5 and 6) and substitute it in the R&D Equation 4. The similar regions assumption ensures that, for each firm, the value of externalities flowing out of the jurisdiction is equivalent to spillovers captured from R&D in all other areas, leading to the technology improvement function presented in Equation 13, which does not contain the spillovers parameters:

$$A_t = A_{t-1} + G_{it}f(b_{it}) + \sum_{J=1}^{n-1} G_{Jt}h(b_{Jt}) = A_{t-1} + (\bar{k}/n)z_t(1 - b_{it})(\theta + b_{it}\gamma) \quad (13)$$

The optimal level of taxation (z_t^{C*}) is obtained by maximizing the national output in Equation 11, subject to the capital constraint and the expected technology improvement

(Equations 12 and 13, respectively). The optimal rate (displayed in Equation 14) 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).

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

(14)

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

(14a)

A third feature that distinguishes the centralized government case is the compensation paid to capital owners. Although firms still compete for capital, they are subject to the same marginal product of capital and tax rate. The applicable interest rate is a function of total capital availability and other parameters of the model, as presented in Equation 15. This rate tends to be lower than the exogenous rate of the decentralized case, as there is no state competition pushing it upward.

$$r^{C*} = \alpha\left(\frac{A_{it}^{C*}}{\bar{k}/n}\right)^{1-\alpha} - z^{C*} = \frac{A_{i,t-1}}{(f^{C*})\left(\bar{k}/n\right)} - \left(f^{C*}(1-\alpha)\right)^{\frac{1-\alpha}{\alpha}}(1-2\alpha) \quad (15)$$

Where $r^{C*} < \bar{r}^R$

(15a)

If we substitute such value in Equation 14, we obtain a different expression for optimal taxes (Equation 16), that can be directly compared to the regional government decision in Equation 8). The first term on the right side of Equation 16 represents the marginal product of capital, that is not affected by the applicable interest rate (unlike the decentralized government case).

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

(16)

The central government's optimal choice for the composition of the public R&D bundle is the one that maximizes technological development in Equation 13, and, consequently, net national output. Equation 17 follows closely the specification of the best choice of the decentralized government (Equation 10), but, however, excluding the parameters of externalities that flow to other provinces.

$$\frac{\partial A_t}{\partial b_t} = 0 \rightarrow b^{C*} = \frac{1}{2} - \frac{\theta}{2\gamma} \quad (17)$$

The economic interpretation of these results is as follows: for small values of (b_t), an increase in basic research spending creates new knowledge that substantially improves the results of applied research. As a result, the central government raises taxes, improves the technology and final net output is increased. Such movement continues until the share of basic research reaches b^{C*}, where the marginal contribution of public R&D equals the cost of an additional unit of tax to output. After such point, the level of applied research to transform additional knowledge in commercial application is insufficient, and further basic research becomes sterile with a negative impact on technological development (as in Aghion and Howitt, 1998, model with secondary innovation). As the contribution of further public R&D to net output falls short of its marginal cost, the government reduces taxes, but aggregate net production is still reduced.

3.4 Effects of decentralization

The main differences between the two 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. The first one is best represented by the optimal composition of the public R&D bundle. While the decision of the central government (Equation 17) is solely based on the basic and applied research productivity parameters, the optimal decentralized decision (Equation 10) weights them according to the level of spillovers applicable to each type of R&D. As a result, the regional government optimally chooses a lower share of basic research, considering that it yields more interjurisdictional externalities (as assumed). This is the first main prediction of the model to be empirically tested in the next section.

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. Conversely, the effect of fiscal decentralization on the share of applied research in the public innovation bundle is positive.*

The optimal level of taxation is also affected by regional spillovers. As the contribution of public R&D to the regional product is smaller than to the national output, regional governments tend to spend less on R&D. This is represented by the value of the R&D productivity factor in Equations 9a and 14a. In the decentralized case, the factor is reduced by the spillover parameters; it is easy to see that $f^{C*} > f^{R*}$.

However, when taxes are defined at the regional level, they also influence the level of capital investment in each region, and this is considered by regional governments. Such effect, however, is ambiguous, as taxes both reduce net capital gain and increase gross marginal product of capital (through technological improvement). Therefore, the overall impact of decentralization on the taxation level or size of the public R&D investment depends on the value of the parameters. This result is in accordance with the conclusions of Kappeler and Välilä (2008), who argued that the final outcome of decentralization cannot be determined theoretically *a priori* in the presence of state competition and interregional spillovers.

Nevertheless, we argue that, in light of the optimal tax rates expressed in Equations 9 and 16, innovation spending tends to be lower in a decentralized environment, for three reasons: first, because state competition acts to limit public spending and government size, as suggested by the 'Leviathan hypothesis';[4] second, because the interest rate tends to be higher in a decentralized government setup (Equation 15a), reducing the remaining funds for both output and technological development; and, finally, because of interregional spillovers. 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. This constitutes the second prediction to be tested in the empirical analysis described in the next section.

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 and of state competition to attract capital.*

[4] This is represented by the interest rate variable in the first term of the decentralized government optimal tax rate (Equation 9).

4 Empirical Analysis

In this section, we present a quantitative analysis to test the two propositions derived from our model. For such purpose, we investigate whether the level of fiscal decentralization has statistically significant effects on government spending on R&D, considering a group of four variables: (a) the share of basic research in the total public budget; (b) the share of 'applied research and development'[5] expenditures; (c) the overall share of R&D spending; and (d) the share of basic research within the public R&D bundle.

4.1 Specification of the empirical model

We assume that the public R&D budget is determined by governments in light of economic, technological and demographic features of the jurisdiction, the political orientation of the party controlling the executive branch, and broader decisions related to the public budget.

As public innovation yields different payoffs for central and regional governments, such decision is also affected by the country's level of fiscal decentralization, which is measured as either the share of subnational levels of government in general government revenue (excluded intergovernmental grants) or the share in total public spending. We consider these two cases of decentralization in separate estimates, as they tend to be highly correlated, reducing the efficiency of the regressions.

However, different studies have argued and 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 size and design of public budgets, mostly due to the 'common pool problem',[6] (Eyraud & Lusinyan, 2013; Borge & Rattsø, 2002). The main effects suggested by the literature are on spending size and fiscal performance (Eyraud & Lusinyan, 2013), but it has also been suggested that vertical fiscal imbalance can be used to correct or compensate for interregional externalities (Boadway & Keen, 1996; Sorens, 2016), such as those arising from public R&D. For this reason, we introduce a variable that represents the vertical imbalance in decentralization, calculated as the difference between

[5] Applied research and development are considered jointly, as they are not distinguished in the IMF Government Finance Statistics database (IMF, 2017).

[6] According to this argument, subnational governments do not internalize the total costs of their expenditures and public services, as part of them is financed by federal funds, thus generating an incentive to overspend.

expenditure and revenue decentralization levels, following the conceptual definition used by Sorens (2016).

We consider that all variables affect government budget decisions contemporaneously, a specification used in different empirical papers (Alegre, 2010; Ashworth et al., 2009; Busemeyer, 2007; Fiva, 2005; Arze del Granado et al., 2016). In addition, as governments may face non-trivial adjustment costs on budget composition, we introduce lagged versions of the dependent variables as explanatory ones to account for path dependency.

On those bases, we use the following reduced-form specification to assess the effects of decentralization on public R&D:

$$dep_var_{it} = \beta_0 + \beta_1 dep_var_{i,t-1} + \beta_2 dec_{it} + c_{it} + f_i + \beta year_t + u_{it} \quad (18)$$

Where

(dep_var_{it}) represents one of the four dependent variables. $basic_{it}$, $applied_{it}$ and rd_{it}^{tot} are the shares of the public budget allocated to basic research, 'applied research and development'[7], and total R&D, respectively; and b_{it} is the intensity of basic research in public R&D spending;

(dec_{it}) is the main explanatory variable of interest, representing the level of decentralization of public revenue (dec_rev_{it}) or expenditure (dec_exp_{it}) of each country; and

$$c_{it} = \beta_3 govsize_{it} + \beta_4 budget_{it} + \beta_5 imbalance_{it} + \beta_6 gdp_{it} + \beta_7 trade_{it} + \beta_8 industry_{it} + \beta_9 unemploy_{it} + \beta_{10} pop_{it} + \beta_{11} educ_{it} + \beta_{12} patent_{it} + \beta_{13} ht_exp_{it} + \beta_{14} orient_right_{it} + \beta_{15} orient_left_{it} \quad (18a)$$

Where (c_{it}) is a vector of control variables that influence or are taken into consideration by the government to determine its R&D budget. Broader decisions on government accounts

[7] Government functions present in the dataset are: public services; defense; public order and safety; economic affairs; environmental affairs; housing and facilities; health; culture; education; and social protection *(IMF, 2017)*.

considered herein are the size of government (public expenditure as share of country's gross domestic product - GDP - $govsize_{it}$), budget balance ($budget_{it}$), and level of decentralization imbalance ($imbalance_{it}$). The variables that represent economic activity are GDP per capita (gdp_{it}), trade openness ($trade_{it}$) - import plus exports as share of GDP, industrialization level or industry value-added as share of GDP ($industry_{it}$), and unemployment levels ($unemploy_{it}$). Population size (pop_{it}) and share of population with tertiary education ($educ_{it}$) are considered to account for demographic and human capital differences. We control for distinct levels of technological development by including variables representing patent application per resident ($patent_{it}$) and high-technology exports as share of manufactured exports (ht_exp_{it}). And, finally, dummies for orientation of the national chief executive party with respect to economic policy ($orient_right_{it}$ and $orient_left_{it}$ for right and left-wing orientations)[8] are also included. Finally, the estimating model also considers country time-invariant features or fixed effects (f_i), time dummies ($year_t$) to account for international trends that affected all nations equally, and an error term (u_{it}).

4.2 Identification Strategy

Almost all empirical studies in our literature review acknowledge that unobservable country features may affect the composition of government spending, which may lead to inconsistent estimates. Following this previous literature, we may also expect endogeneity arising from differences in countries' development levels and other factors. Therefore, we estimate the parameters of interest of Equation 18 using two-step system-GMM (Arellano & Bond, 1991; Arellano & Bover, 1995; Blundell & Bond, 1998), which is largely considered the 'workhorse in estimating dynamic panel data' (Kappeler & Välilä, 2008) and has been used in several related studies (Alegre, 2010; Jia et al., 2014; Sacchi & Salotti, 2016).[9]

[8] Following the definitions presented in Cruz, Keefer, and Scartascini (2016, p. 8): "Right: for parties that are defined as conservative, Christian democratic, or right-wing. Left: for parties that are defined as communist, socialist, social democratic, or left-wing." Dummy variable for center orientation of the chief executive party was excluded to avoid perfect collinearity with other political dummies.

[9] The estimating approach may be intuitively described as follows: the first step is to exclude time-invariant fixed effects (f_i) by first-differencing all variables. However, as this does not solve the problem of endogenous regressors, lagged versions of all variables can be used as instruments, assuming no serial correlation between errors (the original GMM developed by Arellano and Bond 1991). But this assumption is often not valid for dynamic panels (Blundell & Bond, 1998), and for this reason Arellano and Bover (1995) improved the estimator through a system of equations in which lagged differences are used as instruments for equations in levels and vice-versa. Consistency of the estimates is mostly conditioned upon instruments being exogenous, which is commonly assessed through over-identification and second-order correlation in differences tests (Roodman, 2006).

We assume that none of the explanatory variables are exogenous (except for time dummies). Statistical significance is assessed at a 95% confidence level. Considering the gaps in our unbalanced panel, we apply forward orthogonal deviations transformation (Arellano & Bover, 1995); and in light of the limited number of observations, we reduce instrument count by collapsing them into a column vector instrument (Roodman, 2006) and applying principal components analysis (Mehrhoff, 2009). Exogeneity of the instruments is assessed through the Sargan over-identification and Arellano-Bond second-order correlation (AR(2)) tests, and the Kaiser-Meyer-Olkin (KMO) test for sampling adequacy is applied to check whether the instruments chosen are representative of the entire sample.

We also test whether the results obtained in the initial analyses are robust and insensitive to model specification. We run different estimates of Equation 18, gradually excluding each of the explanatory variables from the control matrix, to check if the sign and statistical significance of the fiscal decentralization coefficient remain stable.

4.3 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 of 1995 to 2015[10]. However, comparable data on public innovation spending is still not available for many countries, or in many cases there is information only for a limited number of years. For this reason, our dataset constitutes an unbalanced panel with missing values for different countries and periods.

Table 1 shows the source and descriptive statistics of all variables used in the empirical analysis. Data related to government revenue and spending, including the public R&D dependent variables, come from the IMF Government Finance Statistics database (IMF, 2017). Basic research, applied research and development in this dataset (IMF, 2014) have the same definition presented in OECD (2015). Basic research is classified as part of public services expenditure, and the variable for total 'applied research and development' represents the sum of these expenditures for all functions of government. Total R&D spending constitutes the sum of values for basic research and 'applied research and development'.

[10] List of countries and years presented in Table A1 of the Appendix.

Table 1

Descriptive statistics of variables used in the empirical study

Variable	n	Mean	Std. Dev.	Min	Max	Data Source
Dependent variables – Government R&D categories as share of total government expenditures						
$basic_{it}$	446	0.872	0.699	0.000	3.181	
$applied_{it}$	406	1.204	0.775	0.000	3.638	*IMF Government*
rd_{it}^{tot}	406	2.099	1.071	0.000	5.311	*Finance Statistics (IMF, 2017)*
b_{it}	406	40.292	27.481	0.000	100.000	
Explanatory Variables						
dec_exp_{it}	446	30.365	16.226	0.000	65.630	
dec_rev_{it}	446	16.413	12.372	0.000	51.700	*IMF Government*
$imbalance_{it}$	446	13.952	8.805	-5.270	38.970	*Finance Statistics (IMF, 2017)*
gov_size_{it}	446	42.829	8.206	14.330	63.900	
$budget_{it}$	446	-0.950	4.929	-30.700	19.960	
gdp_{it}	446	31233.360	20509.830	1530.060	117507.800	
$population_{it}$	446	20779.800	27655.050	327.320	143456.900	
$trade_{it}$	446	102.417	53.052	24.490	438.160	*World Bank Development*
$unemploy_{it}$	446	8.202	4.554	0.510	27.470	*Indicators (WB, 2017)*
$industry_{it}$	446	27.808	5.871	10.720	44.800	
$education_{it}$	446	10.955	1.465	2.300	13.400	
$patent_{it}$	446	292.274	383.901	0.098	2271.464	
ht_exp_{it}	446	16.154	10.838	0.000	60.000	
$orient_right_{it}$	446	0.401	0.491	0.000	1.000	*IDB Database of Political*
$orient_left_{it}$	446	0.330	0.471	0.000	1.000	*Institutions 2015 (Cruz et al., 2016)*

4.4 Estimation results

The estimated coefficients for the empirical model and their statistical significance are presented in Table 2 below, along with the results of the over-identification, serial correlation and sampling adequacy tests. In none of the equations 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 Sargan test also does not reject exogeneity of the instruments for any of the regressions. And the Kaiser-Meyer-Olkin test (KMO) 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 increasing consistency of the results.

The first four columns show the results for the expenditure decentralization analysis. We find evidence that this type of decentralization leads to a reduction of government spending on basic research of around 0.02 percentage points (p.p.) per additional point of decentralization. As a consequence, the composition of the public innovation bundle changes, and the intensity of basic research decreases by 0.6 p.p. According to our estimates, expenditure decentralization also negatively affects the share of overall R&D in government spending, with a magnitude of 0.03 p.p. (per additional decentralization point). On the other hand, no evidence of impact on 'applied research and development' spending was found. These results are statistically significant at a 95% confidence level.

Revenue decentralization estimates are displayed in the last four columns of Table 2. We do not find evidence of modification in the composition of public innovation investment, but, on the other hand, its level is negatively affected and by a higher scale than for the case of expenditure decentralization. The share of both basic research and 'applied research and development' in the public budget falls 0.07 p.p. and 0.04 p.p. as revenue becomes more decentralized by one point, leading to an overall decrease of the R&D spending share of 0.07 p.p. All results are significant even at a 99% confidence level.

The estimated parameters are small in the case of total R&D spending, but their economic importance must be assessed in light of the magnitude of the total public R&D budget, that averaged 2.1% of the total government spending in our sample (Table 1). Taking such value into account, our estimates suggest that an additional point of revenue decentralization reduces the public R&D spending by 3,33%, and by 1,52% in the case of revenue decentralization. Therefore, an additional 10 p.p. revenue decentralization should cause public funds dedicated to innovation to fall by a third of its original value (or by 15% in the case of spending decentralization).

Table 2

Estimation results: expenditure and revenue decentralization

	Dependent Variable							
Explanatory	Expenditure Decentralization				Revenue Decentralization			
Variables	$basic_{it}$	$applied_{it}$	rd_{it}^{tot}	b_{it}	$basic_{it}$	$applied_{it}$	rd_{it}^{tot}	b_{it}
$(dep.var.)_{i,t-1}$	0.000	0.000	0.737***	1.029***	0.000	0.000	0.000	0.968*
	(0.000)	(0.000)	(0.060)	(0.126)	(0.000)	(0.000)	(0.000)	(0.565)
dec_{it}	-0.023***	0.016	-0.032**	-0.626**	-0.066***	-0.042***	-0.070***	0.631
	(0.002)	(0.014)	(0.015)	(0.317)	(0.004)	(0.007)	(0.007)	(1.177)
$imbalance_{it}$	-0.000	-0.062***	0.032*	1.071**	-0.071***	0.063***	-0.036***	0.597
	(0.000)	(0.016)	(0.016)	(0.508)	(0.004)	(0.004)	(0.011)	(0.680)
gov_size_{it}	0.000	-0.008	0.031***	0.424	0.022***	-0.040***	0.024***	0.011
	(0.000)	(0.020)	(0.011)	(0.425)	(0.003)	(0.009)	(0.004)	(0.802)
gdp_{it}	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)	(0.001)
$population_{it}$	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)
$trade_{it}$	0.004***	0.026***	-0.005***	0.009	-0.007***	0.008***	0.008***	-0.062
	(0.000)	(0.002)	(0.002)	(0.038)	(0.000)	(0.001)	(0.001)	(0.100)
$unemploy_{it}$	-0.027***	-0.109***	-0.021*	0.055	0.013***	0.000	-0.087***	-1.142
	(0.004)	(0.016)	(0.012)	(0.234)	(0.003)	(0.000)	(0.008)	(1.473)
$orient_right_{it}$	-0.377***	0.147***	0.330***	-1.992	0.425***	-0.272***	-0.138***	1.704
	(0.028)	(0.049)	(0.071)	(2.108)	(0.022)	(0.027)	(0.047)	(2.906)
$orient_left_{it}$	0.000	0.000	0.436***	-4.848**	0.845***	0.000	0.000	1.449
	(0.000)	(0.000)	(0.098)	(2.080)	(0.029)	(0.000)	(0.000)	(6.195)
$industry_{it}$	-0.010***	-0.013	0.000	-0.439	0.061***	0.046***	-0.064***	-1.501
	(0.002)	(0.015)	(0.000)	(0.506)	(0.003)	(0.010)	(0.007)	(1.214)
$education_{it}$	0.000	-0.643***	0.000	-0.919	0.000	0.000	-0.008	-2.166
	(0.000)	(0.068)	(0.000)	(0.962)	(0.000)	(0.000)	(0.031)	(4.673)
$patent_{it}$	0.003***	-0.003***	0.001*	0.013	-0.003***	0.002***	0.004***	-0.013
	(0.000)	(0.000)	(0.000)	(0.009)	(0.000)	(0.000)	(0.000)	(0.029)
ht_exp_{it}	0.030***	0.072***	-0.017	-0.048	0.043***	-0.003	0.104***	0.181
	(0.002)	(0.008)	(0.010)	(0.118)	(0.003)	(0.005)	(0.007)	(0.528)
$budget_{it}$	0.025***	-0.003	0.057***	0.382	0.000	-0.047***	0.000	-0.021
	(0.004)	(0.020)	(0.009)	(0.430)	(0.000)	(0.010)	(0.000)	(1.244)
β_o	0.000	5.607***	0.000	0.000	0.000	0.000	0.000	62.621

	(0.000)	(1.042)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(62.408)
Observations	446	402	402	401	446	402	402	401
Number of countries	41	38	38	38	41	38	38	38
AR(1) test	0.128	0.318	0.367	0.268	.	0.174	0.000	0.440
AR(2) test	0.370	0.709	0.566	0.785	.	0.517	0.751	0.435
Sargan test	0.995	0.688	0.249	1.000	0.967	0.656	0.287	0.997
KMO	0.935	0.911	0.915	0.914	0.926	0.908	0.914	0.912

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes. AR(1), AR(2) and Sargan are the first and second order autocorrelation test and the Sargan overidentification tests, respectively. KMO is the Kaiser-Meyer-Olkin measure of sampling adequacy used to assess the principal components analysis to reduce instruments.

The coefficient for vertical decentralization imbalance is statistically significant in almost all estimates where the fiscal decentralization parameter also is. Our results suggest that the imbalance partially mitigate the effects of expenditure decentralization on the composition of the R&D budget by raising the intensity of basic research, in accordance with the argument of compensation of interregional externalities *(Boadway & Keen, 1996; Sorens, 2016).* On the other hand, vertical imbalance adds to the negative effect of revenue decentralization on the share of basic research and total R&D on the budget,[11] with the opposite effect on applied R&D. The results support our choice of introducing a vertical imbalance variable to consider both types of decentralization, and they suggest that this point deserves to be addressed in greater detail by future research.

The control variables related to economic and demographic features in general present the expected sign. GDP is positively correlated with a higher intensity of R&D in the public budget, as suggested by Romer (1990), raising the share of both basic and applied research. International trade also matters for the definition of public R&D budget: trade openness leads to an increased spending on applied R&D, and high-technology exports suggest higher levels of public basic research. These results confirm the well-accepted link between international trade and technological development, following a group of models that sees trade fostering innovation through factors like market expansion, increasing competition and access to

[11] A possible reason for this result is that, in the case of revenue decentralization, a greater vertical imbalance means a higher level of expenditure decentralization, thus the same direction of effects and coefficients' signs.

overseas' knowledge (Bloom, Draca, & Van Reenen, 2016; Coe & Helpman, 1995; Grossman & Helpman, 1991).

Results of the robustness checks are presented in Tables A2 to A9 of the Appendix (one for each dependent variable, considering both expenditure and revenue decentralization). In these tables, it is possible to see that both the sign and statistical significance of the decentralization variable coefficients change for different regressions. They are particularly affected by the presence (or absence) of variables related to education, technology exports and political orientation. The evidence of our initial results, therefore, is sensitive to the specification of the empirical model, and it cannot be considered robust.

4.5 *Discussion of the Main Findings and Policy Implications*

The results of the *empirical* analysis provide strong support for the two propositions derived from our theoretical model. We find evidence that expenditure decentralization affects the composition of the R&D bundle, resulting in a lower share of basic research. 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 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 the research takes place.

The empirical analysis also presents evidence that total government spending on innovation is negatively impacted by decentralization. The effect is stronger in the case of revenue decentralization. We interpret this as a consequence of the higher influence of regional governments to set tax rates and determine government size. 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).

This latter result is at odds with the 'race to the top' hypothesis in the literature on fiscal decentralization and composition of public budget discussed in section 2. Our study suggests that the incentives of regional governments to spend more on productive activities to

attract capital (Grisorio & Prota, 2015; Sacchi & Salotti, 2016) can be offset by considerable levels of interregional spillovers in the case of ST&I activities.

Overall, the results demonstrate the effects of decentralization on public innovation spending and its composition, a type of expenditure that has not been assessed in previous analyses. This study also contributes to the innovation policy literature discussed in our review of the literature. The negative impact of fiscal decentralization is in accordance with the evidence that innovation presents high levels of spillovers that are not geographically bounded (Bernstein & Nadiri, 1989; Bloom et al., 2013; Mansfield et al., 1977; Wieser, 2005), and that basic research yields more results that are not internalized within regions (Funk, 2002).

Two main relevant policy implications can be derived 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 significant 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 & Schwab, 1997), although this latter cooperative arrangement may not be feasible because of transaction costs and opportunistic behavior. Vertical fiscal imbalance is also an alternative to partially compensate for the effects of expenditure decentralization, as suggested in previous studies and confirmed by our results. However, the effectiveness of such approach may depend on the design of the intergovernmental grants (Sorens, 2016), and it may have other implications on spending and fiscal performance that need to be taken into consideration (Eyraud & Lusinyan, 2013; Borge & Rattsø, 2002).

The second main implication refers to the roles and responsibilities of different levels of government in the design of national strategies for ST&I, or, considering a Schumpeterian perspective, the structure of national systems of innovation (Freeman, 1995). 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 strongly 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.

5 Concluding remarks and further research agenda

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; Lozano and Martínez, 2013), 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 appropriately addressed by this literature. It contributes to the existing knowledge by explaining how decentralization affects the size and composition of public innovation investment. We present a simple 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 show that interregional spillovers lead decentralized governments to dedicate a smaller share of their budget to basic research. The effect of decentralization on the size of spending is expected to be negative in most cases.

We empirically test the implications of the model through an original empirical analysis using panel data across countries. We find evidence that higher levels of expenditure decentralization lead to a lower intensity of basic research in public R&D (an estimated reduction of *0.*6 p.p. per each additional point of expenditure decentralization), and that both types of decentralization negatively affect R&D spending, although the impact is greater for revenue decentralization (3.33% of the average R&D budget in the sample) than for expenditure decentralization (1.52% of the average R&D budget).

The main limitation of this study is the reduced data availability on public innovation spending. Nonetheless, this paper opens a promising research agenda on the links between fiscal decentralization and innovation policy. As more data on this topic becomes available, future studies can improve the empirical analysis, besides considering other variables and theoretical arguments.

In addition, relaxing some of the assumptions of our theoretical model could lead to different outcomes and insights for innovation policy design. For example, government decisions could change if regions are of different sizes or have different levels of development. Also, following the original insights of the fiscal decentralization theorem,

regional governments may have different industrial sectors that require customized innovation policies, which may not be efficiently implemented by a central government, potentially justifying a larger role of decentralized governments in the design and implementation of innovation policies.

References

Aghion, P., & Howitt, P. (1992). A Model of Growth Through Creative Destruction. *Econometrica, 60*(2), 323-351. doi:10.2307/2951599.

Aghion, P., & Howitt, P. (1996). Research and development in the growth process. *Journal of Economic Growth, 1*(1), 49-73.

Aghion, P., & Howitt, P. (1998). *Endogenous growth theory*: MIT press.

Akcigit, U., Hanley, D., & Serrano-Velarde, N. (2013). *Back to basics: Basic research spillovers, innovation policy and growth*. NBER Working Paper, (No. 19473). National Bureau of Economic Research.

Alegre, J. G. (2010). Decentralization and the composition of public expenditure in Spain. *Regional Studies, 44*(8), 1067-1083.

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies, 58*(2), 277-297.

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of econometrics, 68*(1), 29-51.

Arrow, K. (1962). Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity: Economic and social factors* (pp. 609-626): Princeton University Press.

Arze del Granado, F. J., Martinez-Vazquez, J., & McNab, R. M. (2016). Decentralized Governance, Expenditure Composition, and Preferences for Public Goods. *Public Finance Review, 46*(3), 359-388. doi:https://doi.org/10.1177/1091142116639127.

Ashworth, J., Galli, E., & Padovano, F. (2009). Government Decentralization and Public Spending Programs. Paper presented at the XXI conference of the Italian Society of Public Economics (SIEP).

Audretsch, D. B., & Feldman, M. P. (1996). R&D spillovers and the geography of innovation and production. *The American economic review, 86*(3), 630-640.

Auerswald, P. E., Branscomb, L. M., Demos, N., & Min, B. K. (2003). Understanding private-sector decision making for early-stage technology development. *NIST Advanced Technology Program. NIST GCR*.

Bernstein, J. I., & Nadiri, M. I. (1989). Research and development and intra-industry spillovers: an empirical application of dynamic duality. *The Review of Economic Studies, 56*(2), 249-267.

Besley, T., & Coate, S. (2003). Centralized versus decentralized provision of local public goods: a political economy approach. *Journal of public economics, 87*(12), 2611-2637.

Bloom, N., Draca, M., & Van Reenen, J. (2016). Trade induced technical change? The impact of Chinese imports on innovation, IT and productivity. *The Review of Economic Studies, 83*(1), 87-117.

Bloom, N., Schankerman, M., & Van Reenen, J. (2013). Identifying technology spillovers and product market rivalry. *Econometrica, 81*(4), 1347-1393.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of econometrics, 87*(1), 115-143.

Boadway, R., & Keen, M. (1996). Efficiency and the optimal direction of federal-state transfers. *International Tax and Public Finance, 3*(2), 137-155.

Borge, L. E., & Rattsø, J. (2002). Spending growth with vertical fiscal imbalance: decentralized government spending in Norway, 1880–1990. *Economics & Politics, 14*(3), 351-373.

Brennan, G., & Buchanan, J. M. (1980). *The power to tax: Analytic foundations of a fiscal constitution*: Cambridge University Press.

Busemeyer, M. R. (2007). Determinants of public education spending in 21 OECD democracies, 1980–2001. *Journal of European Public Policy, 14*(4), 582-610.

Chu, A. C., & Furukawa, Y. (2013). Patentability and knowledge spillovers of basic R&D. *Southern Economic Journal, 79*(4), 928-945.

Coe, D. T., & Helpman, E. (1995). International R&D spillovers. *European Economic Review, 39*(5), 859-887.

Coe, D. T., Helpman, E., & Hoffmaister, A. W. (2009). International R&D spillovers and institutions. *European Economic Review, 53*(7), 723-741.

Cozzi, G., & Galli, S. (2009). Science-based R&D in Schumpeterian Growth. *Scottish Journal of Political Economy, 56*(4), 474-491.

Cruz, C., Keefer, P., & Scartascini, C. (2016). The Database of Political Institutions 2015 (DPI 2015) In.

Dhillon, A., Wooders, M., & Zissimos, B. (2007). Tax competition reconsidered. *Journal of Public Economic Theory, 9*(3), 391-423.

Diaz-Cayeros, A., McElwain, K. M., Romero, V., & Siewierski, K. A. (2002). *Fiscal Decentralization, and Particularistic Spending across Countries.* Paper presented at the Conference on "Comparative Analysis of Political Institutions", Princeton University, Princeton, NJ, USA.

Edler, J., Cunningham, P., Gök, A., & Shapira, P. (2013). Impacts of innovation policy: synthesis and conclusions. *Compendium of Evidence on the Effectiveness of Innovation Policy Intervention Project) Manchester*.

Edler, J., & Fagerberg, J. (2017). Innovation policy: what, why, and how. *Oxford Review of Economic Policy, 33*(1), 2-23.

Eyraud, L., & Lusinyan, L. (2013). Vertical fiscal imbalances and fiscal performance in advanced economies. *Journal of Monetary Economics, 60*(5), 571-587.

Fagerberg, J. (2017). Innovation policy: Rationales, lessons and challenges. *Journal of Economic Surveys, 31*(2), 497-512.

Faguet, J.P. (2004). Does decentralization increase government responsiveness to local needs?: Evidence from Bolivia. *Journal of public economics, 88*(3), 867-893.

Feidler, J., & Staal, K. (2012). Centralized and decentralized provision of public goods. *Economics of Governance, 13*(1), 73-93.

Fiva, J. H. (2005). New evidence on fiscal decentralization and the size of government.

Freeman, C. (1995). The 'National System of Innovation'in historical perspective. *Cambridge Journal of economics, 19*(1), 5-24.

Funk, M. (2002). Basic research and international spillovers. *International Review of Applied Economics, 16*(2), 217-226.

Furman, J. L., Kyle, M. K., Cockburn, I. M., & Henderson, R. (2006). *Public & private spillovers, location and the productivity of pharmaceutical research*. NBER Working Paper, (No. 12509). National Bureau of Economic Research.

Griliches, Z. (1985). Productivity, R&D, and basic research at the firm level in the 1970s. In: National Bureau of Economic Research Cambridge, Mass., USA.

Grisorio, M. J., & Prota, F. (2015). The short and the long run relationship between fiscal decentralization and public expenditure composition in Italy. *Economics Letters, 130*, 113-116.

Grossman, G. M., & Helpman, E. (1991). Quality Ladders in the Theory of Growth. *Review of Economic Studies, 58*(1), 43-61. doi:10.2307/2298044.

Habibi, N., Huang, C., Miranda, D., Murillo, V., Ranis, G., Sarkar, M., & Stewart, F. (2003). Decentralization and human development in Argentina. *Journal of Human Development, 4*(1), 73-101.

Hall, B. H., Mairesse, J., & Mohnen, P. (2010). Measuring the Returns to R&D. *Handbook of the Economics of Innovation, 2*, 1033-1082.

Hulten, C. R., & Schwab, R. M. (1997). A fiscal federalism approach to infrastructure policy. *Regional Science and Urban Economics, 27*(2), 139-159.

IMF (2014). Government finance statistics manual 2014. In. Washington, D.C.: International Monetary Fund.

IMF (2017). *IMF Government Finance Statistics*. Retrieved from: http://data.imf.org/?sk=a0867067-d23c-4ebc-ad23-d3b015045405.

Jaffe, A. B., Trajtenberg, M., & Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *the Quarterly journal of Economics, 108*(3), 577-598.

Jia, J., Guo, Q., & Zhang, J. (2014). Fiscal decentralization and local expenditure policy in China. *China Economic Review, 28*(C), 107-122.

Kappeler, A., & Välilä, T. (2008). Fiscal federalism and the composition of public investment in Europe. *European Journal of Political Economy, 24*(3), 562-570.

Katz, J. S. (1994). Geographical proximity and scientific collaboration. *Scientometrics, 31*(1), 31-43.

Keen, M., & Marchand, M. (1997). Fiscal competition and the pattern of public spending. *Journal of public economics, 66*(1), 33-53.

Köhler, C., Laredo, P., & Rammer, C. (2012). The impact and effectiveness of fiscal incentives for R&D. *Compendium of Evidence on the effectiveness of Innovation Policy*.

Lichtenberg, F. R., & Siegel, D. (1991). The impact of R&D investment on productivity–New evidence using linked R&D–LRD data. *Economic Inquiry, 29*(2), 203-229.

Lozano, I., & Martínez, M. (2013). *Enrollment and quality levels of Colombia's public basic education: has fiscal decentralization improved them?* Borradores de Economía, (747).

Malerba, F., Mancusi, M. L., & Montobbio, F. (2013). Innovation, international R&D spillovers and the sectoral heterogeneity of knowledge flows. *Review of World Economics, 149*(4), 697-722.

Mancusi, M. L. (2008). International spillovers and absorptive capacity: A cross-country cross-sector analysis based on patents and citations. *Journal of International Economics, 76*(2), 155-165.

Mansfield, E. (1980). Basic research and productivity increase in manufacturing. *The American economic review, 70*(5), 863-873.

Mansfield, E. (1991). Academic research and industrial innovation. *Research Policy, 20*(1), 1-12.

Mansfield, E., & Lee, J.-Y. (1996). The modern university: contributor to industrial innovation and recipient of industrial R&D support. *Research Policy, 25*(7), 1047-1058.

Mansfield, E., Rapoport, J., Romeo, A., Wagner, S., & Beardsley, G. (1977). Social and Private Rates of Return from Industrial Innovations. *the Quarterly journal of Economics, 91*(2), 221-240.

Martinez-Vazquez, J., Lago-Peñas, S., & Sacchi, A. (2017). The impact of fiscal decentralization: A survey. *Journal of Economic Surveys, 31*(4), 1095-1129.

Maurseth, P. B., & Verspagen, B. (2002). Knowledge spillovers in Europe: a patent citations analysis. *The Scandinavian journal of economics, 104*(4), 531-545.

Mehrhoff, J. (2009). A solution to the problem of too many instruments in dynamic panel data GMM.

Morales, M. F. (2004). Research policy and endogenous growth. *Spanish Economic Review, 6*(3), 179-209.

Nelson, R. R. (1959). The simple economics of basic scientific research. *Journal of Political Economy, 67*(3), 297-306.

Oates, W. E. (1972). Fiscal Federalism New York. *Har-court Brace Jovanovich*.

Oates, W. E. (1999). An essay on fiscal federalism. *Journal of economic literature, 37*(3), 1120-1149.

Oates, W. E. (2008a). On the evolution of fiscal federalism: theory and institutions. *National Tax Journal, 61*(2), 313-334.

Oates, W. E. (2008b). On the theory and practice of fiscal decentralization. *Institutional foundations of public finance: Economic and legal perspectives, 165*, 176.

Oates, W. E., & Schwab, R. M. (1988). Economic competition among jurisdictions: efficiency enhancing or distortion inducing? *Journal of public economics, 35*(3), 333-354.

OECD. (2014). *OECD Science, Technology and Industry Outlook 2014*: OECD Publishing.

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

OECD. (2016). *Fiscal Federalism 2016: Making Decentralization Work*. Paris: OECD Publishing.

Park, W. G. (1998). A theoretical model of government research and growth. *Journal of Economic Behavior & Organization, 34*(1), 69-85.

Peri, G. (2005). Determinants of knowledge flows and their effect on innovation. *The review of Economics and Statistics, 87*(2), 308-322.

Ponce-Rodriguez, R., Hankla, C. R., Martinez-Vazquez, J., & Heredia-Ortiz, E. (2018). Rethinking the political economy of decentralization: how elections and parties shape the provision of local public goods. *Publius: The Journal of Federalism* (forthcoming).

Romer, P. M. (1990). Endogenous Technological Change. *Journal of Political Economy, 98*(5), S71-S102. doi:10.1086/261725.

Roodman, D. (2006). How to do xtabond2: An introduction to difference and system GMM in Stata.

Sacchi, A., & Salotti, S. (2016). A comprehensive analysis of expenditure decentralization and of the composition of local public spending. *Regional Studies, 50*(1), 93-109.

Salter, A. J., & Martin, B. R. (2001). The economic benefits of publicly funded basic research: a critical review. *Research Policy, 30*(3), 509-532.

Shapiro, S., & Taylor, J. (2013). *Federal R & D: Analyzing the Shift From Basic and Applied Research Toward Development.* Honors Thesis 2013, Retrieved from http://economics.stanford.edu/files/Theses/SamShapiroHonorsThesis-May2013.pdf .

Sinn, H.-W. (2003). The New Systems Competition, Yrjo Jahnsson Lectures, Helsinki 1999. In: Blackwell Publishing, Oxford.

Sorens, J. (2016). *Vertical fiscal gaps and economic performance: A theoretical Review and an Empirical Meta-analysis*. Mercatus Working Paper. Arlington, VA.

Tiebout, C. (1956). A Pure Theory of Local Expenditures. Journal of Political Economy, 64(5), 416–424.

U.S. JEC (2010). *The 2010 Joint Economic Report*. Retrieved from Washington DC.: https://www.jec.senate.gov/public/_cache/files/1f859d11-f43b-4dd6-9f8b-a90199b02841/2010-joint-economic-committee-annual-report.pdf.

Verspagen, B. (1992). Endogenous innovation in neoclassical growth models: a survey. *Journal of Macroeconomics, 14*(4), 631-662.

Verspagen, B., & De Loo, I. (1999). Technology spillovers between sectors. *Technological Forecasting and Social Change, 60*(3), 215-235.

WB, (2017). *World Development Indicators*. Retrieved from: https://data.worldbank.org/indicator

Wieser, R. (2005). Research and development productivity and spillovers: empirical evidence at the firm level. *Journal of Economic Surveys, 19*(4), 587-621.

Young, A. (1992). A tale of two cities: factor accumulation and technical change in Hong Kong and Singapore. *NBER macroeconomics annual, 7*, 13-54.

Zodrow, G. R., & Mieszkowski, P. (1986). Pigou, Tiebout, property taxation, and the underprovision of local public goods. *Journal of urban economics, 19*(3), 356-370.

Appendix

Table A1

List of countries and years used in the empirical study

Country	Years
Albania	2012, 2013, 2014, 2015
Austria	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015
Belarus	2015
Belgium	2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Bhutan	2011, 2012
Bulgaria	1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Cyprus	2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Czech Republic	2015
Denmark	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015
El Salvador	2015
Estonia	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Finland	2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
France	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Georgia	2005, 2015
Germany	2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015
Greece	2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015
Hungary	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Iceland	2014
Ireland	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Italy	2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Japan	2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Kazakhstan	2011, 2012, 2013, 2014, 2015
Latvia	2008, 2009, 2010, 2011, 2012, 2013, 2014
Lithuania	2001, 2002, 2003, 2004, 2005, 2006, 2007
Luxembourg	2013, 2014, 2015
Malta	2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Moldova	2014, 2015
Netherlands	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Norway	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012 , 2013, 2014, 2015
Poland	2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Portugal	1996, 1997, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2010, 2011, 2012, 2013, 2014
Romania	2010, 2011, 2012, 2013, 2014
Russian Federation	2015
Slovak Republic	2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Slovenia	2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
South Africa	2013, 2014, 2015
Spain	1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2014, 2015
Sweden	2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015
Switzerland	1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014
Ukraine	2015
United Kingdom	1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015

Source: IMF Government Finance Statistics (IMF, 2017); World Bank Development Indicators (WB, 2017); IDB Database of Political Institutions 2015 (Cruz, Keefer, and Scartascini, 2016).

Table A2

Robustness Check. dependent variable: basic research as share of total government spending ($basic_{it}$); expenditure decentralization

Explanatory Variables	Coefficients, standard errors and statistical significance												
$(dep.var.)_{i,t-1}$	0.000	0.953***	0.995***	0.297***	1.144***	0.986***	0.857***	0.959***	0.840***	0.910***	0.891***	0.955***	0.998***
	(0.000)	(0.173)	(0.149)	(0.078)	(0.064)	(0.097)	(0.114)	(0.050)	(0.076)	(0.077)	(0.042)	(0.017)	(0.031)
dec_{it}	-0.023***	0.055**	-0.000	-0.189***	0.004	0.002	-0.005	-0.007	-0.008	-0.013	-0.006	-0.002	0.006
	(0.002)	(0.026)	(0.020)	(0.017)	(0.006)	(0.011)	(0.016)	(0.010)	(0.013)	(0.009)	(0.004)	(0.004)	(0.006)
$imbalance_{it}$	-0.000	-0.095**	0.006	0.153***	0.025***	0.009	0.019	0.010	0.012	0.014	0.016**	0.007	-0.011
	(0.000)	(0.044)	(0.028)	(0.014)	(0.008)	(0.010)	(0.018)	(0.012)	(0.014)	(0.010)	(0.008)	(0.010)	(0.009)
gov_size_{it}	0.000	0.010	-0.012	0.021***	-0.004	-0.005	-0.005	0.001	-0.002	-0.002	0.001	0.006**	
	(0.000)	(0.021)	(0.009)	(0.005)	(0.004)	(0.007)	(0.011)	(0.007)	(0.007)	(0.006)	(0.003)	(0.002)	
gdp_{it}	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)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
$population_{it}$	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)	(0.000)	(0.000)	(0.000)	(0.000)			
$trade_{it}$	0.004***	-0.004	0.002	-0.013***	0.003***	0.002	0.002	0.001	0.002*				
	(0.000)	(0.005)	(0.004)	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)				
$unemploy_{it}$	-0.027***	0.002	0.002	-0.121***	0.007	0.006	0.016	-0.000					
	(0.004)	(0.023)	(0.012)	(0.013)	(0.007)	(0.012)	(0.011)	(0.008)					
$orient\ right_{it}$	-0.377***	0.296	-0.089	0.489***	-0.148***	-0.069	-0.038						
	(0.028)	(0.183)	(0.123)	(0.068)	(0.047)	(0.086)	(0.055)						
$orient_left_{it}$	0.000	0.395*	-0.079	-0.586***	-0.018	-0.016							
	(0.000)	(0.218)	(0.168)	(0.091)	(0.041)	(0.091)							
$industry_{it}$	-0.010***	-0.046	-0.011	-0.071***	-0.015***								
	(0.002)	(0.044)	(0.015)	(0.011)	(0.004)								
$education_{it}$	0.000	0.196***	0.052	0.467***									
	(0.000)	(0.072)	(0.074)	(0.049)									
$patent_{it}$	0.003***	-0.003*	-0.000										
	(0.000)	(0.002)	(0.000)										
$ht\ exp_{it}$	0.030***	0.017											
	(0.002)	(0.011)											
$budget_{it}$	0.025***												
	(0.004)												
β_o	0.000	-0.445	0.000	0.000	0.000	0.000	-0.517	0.855	0.156	-0.074	0.000	-0.186	-0.179
	(0.000)	(16.718)	(0.000)	(0.000)	(0.000)	(0.000)	(2.049)	(1.157)	(10.485)	(2.280)	(0.000)	(0.128)	(0.183)
Observations	446	446	450	450	450	454	454	454	454	455	455	455	455
Number of countries	41	41	41	41	41	42	42	42	42	43	43	43	43

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes.

Table A3

Robustness Check. dependent variable: applied research as share of total government spending ($applied_{it}$); expenditure decentralization

Explanatory Variables	Coefficients, standard errors and statistical significance												
$(dep.var.)_{i,t-1}$	0.000	0.326	0.743***	0.729***	0.000	0.911***	0.000	0.576***	0.504**	0.876***	0.684***	0.816***	0.860***
	(0.000)	(0.329)	(0.155)	(0.191)	(0.000)	(0.086)	(0.000)	(0.200)	(0.249)	(0.210)	(0.217)	(0.096)	(0.147)
dec_{it}	0.016	0.013	0.007	0.019	0.057***	-0.000	0.014*	-0.022	-0.087**	-0.135***	-0.086	0.011	0.026
	(0.014)	(0.043)	(0.008)	(0.019)	(0.021)	(0.023)	(0.008)	(0.034)	(0.039)	(0.041)	(0.066)	(0.010)	(0.024)
$imbalance_{it}$	-0.062***	0.017	0.017	-0.016	-0.074***	-0.005	-0.000	0.018	0.074***	0.077**	0.119	-0.009	0.004
	(0.016)	(0.068)	(0.013)	(0.027)	(0.026)	(0.028)	(0.000)	(0.029)	(0.024)	(0.030)	(0.091)	(0.015)	(0.034)
gov_size_{it}	-0.008	-0.033	-0.016	-0.012	-0.009	-0.015	-0.037***	0.001	0.059**	0.065	-0.001	-0.006	
	(0.020)	(0.026)	(0.015)	(0.030)	(0.014)	(0.011)	(0.010)	(0.018)	(0.028)	(0.042)	(0.018)	(0.007)	
gdp_{it}	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)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
$population_{it}$	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)	(0.000)	(0.000)	(0.000)	(0.000)			
$trade_{it}$	0.026***	0.009	0.005**	0.005*	0.001	-0.000	0.013***	0.007**	0.013**				
	(0.002)	(0.014)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.005)				
$unemploy_{it}$	-0.109***	-0.015	0.021	-0.036	-0.043	-0.011	-0.028	-0.039					
	(0.016)	(0.093)	(0.023)	(0.041)	(0.031)	(0.012)	(0.018)	(0.026)					
$orient\ right_{it}$	0.147***	-0.708	-0.126***	0.151	0.418**	-0.044	-0.036						
	(0.049)	(0.744)	(0.046)	(0.245)	(0.164)	(0.152)	(0.069)						
$orient_left_{it}$	0.000	-0.440	0.000	0.265	0.664***	0.182							
	(0.000)	(0.753)	(0.000)	(0.342)	(0.203)	(0.201)							
$industry_{it}$	-0.013	-0.021	-0.009	0.001	0.007								
	(0.015)	(0.125)	(0.010)	(0.052)	(0.014)								
$education_{it}$	-0.643***	0.582	-0.003	-0.042									
	(0.068)	(0.653)	(0.045)	(0.102)									
$patent_{it}$	-0.003***	0.004	0.000										
	(0.000)	(0.004)	(0.001)										
$ht\ exp_{it}$	0.072***	-0.002											
	(0.008)	(0.060)											
$budget_{it}$	-0.003												
	(0.020)												
β_o	5.607***	-3.159	0.000	0.225	0.000	0.616	0.000	0.000	0.000	2.606	-11.077	0.000	5.875
	(1.042)	(4.109)	(0.000)	(3.700)	(0.000)	(0.704)	(0.000)	(0.000)	(0.000)	(27.610)	(8.892)	(0.000)	(3.633)
Observations	402	402	406	406	406	408	408	408	408	409	409	409	409
Number of countries	38	38	38	38	38	38	38	38	38	39	39	39	39

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes.

Table A4

Robustness Check. dependent variable: public R&D as share of total government spending (rd_{it}^{tot}); expenditure decentralization

Explanatory Variables	Coefficients, standard errors and statistical significance												
$(dep.var.)_{i,t-1}$	0.737***	0.000	0.000	0.000	0.784***	0.000	-1.015***	0.620***	0.646***	0.811***	1.031***	0.942***	0.986***
	(0.060)	(0.000)	(0.000)	(0.000)	(0.113)	(0.000)	(0.255)	(0.231)	(0.154)	(0.240)	(0.116)	(0.101)	(0.106)
dec_{it}	-0.032**	0.035***	0.025	0.084***	-0.007	0.084***	-0.230***	-0.066	-0.034	-0.093**	-0.045	0.038	0.031
	(0.015)	(0.005)	(0.019)	(0.013)	(0.026)	(0.013)	(0.031)	(0.064)	(0.031)	(0.042)	(0.045)	(0.040)	(0.038)
$imbalance_{it}$	0.032*	-0.074***	-0.043*	-0.100***	-0.006	-0.074***	0.084***	0.089**	0.060***	0.094***	0.045	-0.037	0.001
	(0.016)	(0.012)	(0.025)	(0.015)	(0.048)	(0.015)	(0.022)	(0.044)	(0.020)	(0.033)	(0.050)	(0.064)	(0.040)
gov_size_{it}	0.031***	0.014**	-0.048***	-0.015	-0.022	-0.069***	0.084***	0.006	-0.002	-0.004	0.001	0.002	
	(0.011)	(0.007)	(0.011)	(0.009)	(0.019)	(0.007)	(0.022)	(0.041)	(0.021)	(0.041)	(0.023)	(0.016)	
gdp_{it}	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)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
$population_{it}$	-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)	(0.000)	(0.000)	(0.000)	(0.000)			
$trade_{it}$	-0.005***	0.015***	0.005***	0.004*	0.002	0.017***	-0.007*	0.009	0.010***				
	(0.002)	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)	(0.004)	(0.007)	(0.004)				
$unemploy_{it}$	-0.021*	-0.072***	-0.072***	0.053***	-0.012	-0.034**	-0.225***	0.010					
	(0.012)	(0.005)	(0.011)	(0.008)	(0.015)	(0.016)	(0.032)	(0.073)					
$orient\ right_{it}$	0.330***	0.621***	-0.006	0.716***	0.120	0.663***	-0.057						
	(0.071)	(0.044)	(0.042)	(0.103)	(0.171)	(0.120)	(0.060)						
$orient_left_{it}$	0.436***	0.857***	0.000	0.788***	0.114	0.804***							
	(0.098)	(0.067)	(0.000)	(0.132)	(0.182)	(0.129)							
$industry_{it}$	0.000	0.000	0.059***	0.043***	0.021								
	(0.000)	(0.000)	(0.011)	(0.008)	(0.020)								
$education_{it}$	0.000	-0.221***	-0.049	-0.075***									
	(0.000)	(0.016)	(0.036)	(0.028)									
$patent_{it}$	0.001*	0.000	0.004***										
	(0.000)	(0.000)	(0.001)										
$ht\ exp_{it}$	-0.017	0.059***											
	(0.010)	(0.005)											
$budget_{it}$	0.057***												
	(0.009)												
β_o	0.000	0.000	0.000	0.000	0.000	0.000	12.637***	-2.072	-3.335	10.957	2.230	-1.944	5.812
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(1.582)	(14.575)	(2.305)	(19.313)	(2.642)	(1.816)	(6.114)
Observations	402	402	406	406	406	408	408	408	408	409	409	409	409
Number of countries	38	38	38	38	38	38	38	38	38	39	39	39	39

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes.

Table A5

Robustness Check. dependent variable: basic research as share of total public R&D spending (b_{it}); expenditure decentralization

Explanatory Variables	Coefficients, standard errors and statistical significance												
$(dep.var.)_{i,t-1}$	1.029***	0.930***	0.936***	1.040***	0.933***	0.678	0.949***	0.668***	0.689***	0.952***	0.920***	0.899***	0.952***
	(0.126)	(0.046)	(0.047)	(0.196)	(0.165)	(0.445)	(0.078)	(0.167)	(0.134)	(0.062)	(0.051)	(0.051)	(0.058)
dec_{it}	-0.626**	-0.178***	0.092	0.916	-0.407	-1.818**	0.202	-0.282	-0.345	-0.012	-0.117	-0.086	0.098
	(0.317)	(0.052)	(0.100)	(1.014)	(0.593)	(0.793)	(0.261)	(0.424)	(0.520)	(0.188)	(0.190)	(0.170)	(0.311)
$imbalance_{it}$	1.071**	0.017	-0.285	-1.360	0.701	2.658	0.080	0.821	0.646	0.114	0.384	-0.139	0.087
	(0.508)	(0.130)	(0.204)	(1.665)	(0.610)	(1.668)	(0.363)	(0.562)	(0.614)	(0.306)	(0.405)	(0.296)	(0.664)
gov_size_{it}	0.424	-0.034	-0.023	-0.453	-0.157	1.074	0.012	-0.002	0.199	-0.009	0.009	-0.036	
	(0.425)	(0.094)	(0.048)	(0.410)	(0.237)	(0.695)	(0.131)	(0.281)	(0.536)	(0.081)	(0.124)	(0.155)	
gdp_{it}	-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)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
$population_{it}$	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)	(0.000)	(0.000)	(0.000)	(0.000)			
$trade_{it}$	0.009	-0.007	0.017	0.115*	0.111***	0.191	0.012	0.039	0.015				
	(0.038)	(0.023)	(0.016)	(0.068)	(0.040)	(0.155)	(0.033)	(0.041)	(0.137)				
$unemploy_{it}$	0.055	0.102	0.000	-0.280	0.192	0.396	-0.148	0.408					
	(0.234)	(0.116)	(0.000)	(0.846)	(0.359)	(1.730)	(0.473)	(0.496)					
$orient\ right_{it}$	-1.992	1.219**	1.695**	0.271	-2.964	-1.097	0.782						
	(2.108)	(0.477)	(0.775)	(3.683)	(2.531)	(11.114)	(1.099)						
$orient_left_{it}$	-4.848**	-0.426	0.999*	-0.072	-5.553*	-8.919							
	(2.080)	(0.737)	(0.601)	(5.062)	(3.231)	(10.424)							
$industry_{it}$	-0.439	0.370***	0.000	0.002	-0.087								
	(0.506)	(0.110)	(0.000)	(0.424)	(0.371)								
$education_{it}$	-0.919	0.000	0.000	-1.117									
	(0.962)	(0.000)	(0.000)	(1.706)									
$patent_{it}$	0.013	-0.005	-0.009***										
	(0.009)	(0.004)	(0.003)										
$ht\ exp_{it}$	-0.048	-0.067											
	(0.118)	(0.066)											
$budget_{it}$	0.382												
	(0.430)												
β_o	0.000	0.000	0.000	0.000	0.000	-51.530	0.000	-20.135	-2.973	0.000	0.000	538.993	-3.557
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(65.504)	(0.000)	(39.196)	(409.048)	(0.000)	(0.000)	(976.916)	(9.083)
Observations	401	401	405	405	405	407	407	407	407	407	407	407	407
Number of countries	38	38	38	38	38	38	38	38	38	38	38	38	38

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes.

Table A6

Robustness Check. dependent variable: basic research as share of total government spending ($basic_{it}$); revenue decentralization

Explanatory variables	Coefficients, standard errors and statistical significance												
$(dep.var.)_{i,t-1}$	0.000	0.000	0.000	0.000	0.561***	1.540***	0.823***	0.000	0.907***	0.000	0.925***	0.982***	0.950***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.061)	(0.057)	(0.138)	(0.000)	(0.045)	(0.000)	(0.055)	(0.021)	(0.037)
dec_{it}	-0.066***	-0.052***	-0.145***	-0.110***	0.002	0.034***	0.002	-0.031***	-0.007	-0.052***	-0.005	-0.024***	0.008
	(0.004)	(0.001)	(0.005)	(0.007)	(0.009)	(0.003)	(0.022)	(0.003)	(0.007)	(0.004)	(0.004)	(0.006)	(0.005)
$imbalance_{it}$	-0.071***	0.044***	0.144***	0.022***	-0.006	-0.021***	0.010	0.031***	-0.006	-0.003	0.010	0.008***	-0.006*
	(0.004)	(0.002)	(0.007)	(0.007)	(0.007)	(0.004)	(0.009)	(0.004)	(0.005)	(0.004)	(0.007)	(0.003)	(0.004)
gov_size_{it}	0.022***	0.051***	0.020***	-0.030***	-0.015***	-0.038***	-0.002	0.014***	-0.010**	0.033***	0.000	0.002	
	(0.003)	(0.001)	(0.003)	(0.003)	(0.005)	(0.002)	(0.008)	(0.003)	(0.005)	(0.003)	(0.003)	(0.003)	
gdp_{it}	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)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
$population_{it}$	-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)	(0.000)	(0.000)	(0.000)	(0.000)			
$trade_{it}$	-0.007***	0.007***	0.027***	-0.007***	-0.000	0.004***	0.001	-0.006***	0.001				
	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)				
$unemploy_{it}$	0.013***	0.026***	0.169***	0.027***	0.014***	0.032***	0.001	-0.002					
	(0.003)	(0.002)	(0.006)	(0.005)	(0.005)	(0.003)	(0.007)	(0.003)					
$orient\ right_{it}$	0.425***	-0.036***	0.355***	0.139***	-0.076*	-0.447***	-0.031						
	(0.022)	(0.009)	(0.028)	(0.033)	(0.041)	(0.031)	(0.067)						
$orient_left_{it}$	0.845***	0.000	-0.635***	-0.116**	0.091**	-0.033							
	(0.029)	(0.000)	(0.042)	(0.047)	(0.045)	(0.027)							
$industry_{it}$	0.061***	0.050***	0.136***	-0.068***	0.011**								
	(0.003)	(0.001)	(0.004)	(0.011)	(0.005)								
$education_{it}$	0.000	-0.357***	-0.756***	0.451***									
	(0.000)	(0.007)	(0.022)	(0.029)									
$patent_{it}$	-0.003***	-0.001***	-0.003***										
	(0.000)	(0.000)	(0.000)										
$ht\ exp_{it}$	0.043***	0.006***											
	(0.003)	(0.001)											
$budget_{it}$	0.000												
	(0.000)												
β_o	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.477*	0.000	0.000	0.874***	-0.352**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.279)	(0.000)	(0.000)	(0.331)	(0.163)
Observations	446	446	450	450	450	454	454	454	454	455	455	455	455
Number of countries	41	41	41	41	41	42	42	42	42	43	43	43	43

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes.

Table A7

Robustness Check. dependent variable: applied research as share of total government spending ($applied_{it}$); revenue decentralization

Explanatory variables	Coefficients, standard errors and statistical significance												
$(dep.var.)_{i,t-1}$	0.000	1.047	0.000	0.857***	0.871***	0.759***	0.000	0.841***	0.857***	0.910***	0.631***	0.947***	0.000
	(0.000)	(0.802)	(0.000)	(0.095)	(0.075)	(0.056)	(0.000)	(0.156)	(0.270)	(0.321)	(0.198)	(0.144)	(0.000)
dec_{it}	-0.042***	0.126	0.105***	-0.019	-0.031	0.010	-0.047***	-0.038	-0.074*	-0.072	-0.005	-0.014	0.019***
	(0.007)	(0.199)	(0.022)	(0.022)	(0.028)	(0.015)	(0.015)	(0.029)	(0.041)	(0.050)	(0.032)	(0.033)	(0.000)
$imbalance_{it}$	0.063***	-0.045	-0.098***	-0.007	-0.011	0.004	0.005	-0.011	0.001	-0.020	-0.003	0.014	0.090***
	(0.004)	(0.074)	(0.014)	(0.011)	(0.017)	(0.008)	(0.007)	(0.016)	(0.021)	(0.043)	(0.018)	(0.012)	(0.000)
gov_size_{it}	-0.040***	0.069	-0.036***	-0.002	0.001	-0.008	0.002	-0.000	0.037	-0.002	-0.007	0.010	
	(0.009)	(0.075)	(0.011)	(0.010)	(0.013)	(0.008)	(0.009)	(0.017)	(0.040)	(0.036)	(0.013)	(0.010)	
gdp_{it}	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)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
$population_{it}$	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)	(0.000)	(0.000)	(0.000)	(0.000)			
$trade_{it}$	0.008***	-0.002	0.011***	0.002	0.000	0.002*	0.008***	0.001	0.003				
	(0.001)	(0.007)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)	(0.003)	(0.005)				
$unemploy_{it}$	0.000	0.060	-0.104***	-0.015	-0.020	-0.015	-0.057***	-0.010					
	(0.000)	(0.049)	(0.013)	(0.010)	(0.019)	(0.014)	(0.010)	(0.029)					
$orient\ right_{it}$	-0.272***	1.401	1.044***	0.147	0.071	0.000	-0.053						
	(0.027)	(1.877)	(0.121)	(0.108)	(0.105)	(0.000)	(0.064)						
$orient_left_{it}$	0.000	1.124	1.800***	0.206	0.153	0.209***							
	(0.000)	(1.403)	(0.186)	(0.140)	(0.124)	(0.080)							
$industry_{it}$	0.046***	-0.120	0.147***	0.014	0.009								
	(0.010)	(0.235)	(0.018)	(0.010)	(0.017)								
$education_{it}$	0.000	0.357	-0.346***	-0.049									
	(0.000)	(0.551)	(0.045)	(0.040)									
$patent_{it}$	0.002***	-0.013	-0.000										
	(0.000)	(0.020)	(0.000)										
$ht\ exp_{it}$	-0.003	0.028											
	(0.005)	(0.066)											
$budget_{it}$	-0.047***												
	(0.010)												
β_o	0.000	-13.519	0.000	0.000	0.000	0.000	0.000	0.000	-6.133	8.048	0.347	-0.884	0.000
	(0.000)	(12.889)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(5.456)	(24.705)	(3.377)	(0.763)	(0.000)
Observations	402	402	406	406	406	408	408	408	408	409	409	409	409
Number of countries	38	38	38	38	38	38	38	38	38	39	39	39	39

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes.

Table A8

Robustness Check. dependent variable: public R&D as share of total government spending (rd_{it}^{tot}); revenue decentralization

Explanatory variables	Coefficients, standard errors and statistical significance												
$(dep.var.)_{i,t-1}$	0.000	0.000	0.000	0.000	0.746***	0.986***	1.344***	0.789***	0.749***	0.843***	0.888***	0.000	1.222***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.070)	(0.060)	(0.109)	(0.117)	(0.206)	(0.231)	(0.088)	(0.000)	(0.049)
dec_{it}	-0.070***	0.000	0.006	0.235***	-0.099***	0.003	-0.016	0.008	0.031	-0.053	-0.069*	0.020***	-0.028***
	(0.007)	(0.008)	(0.009)	(0.018)	(0.036)	(0.015)	(0.018)	(0.012)	(0.065)	(0.080)	(0.036)	(0.001)	(0.005)
$imbalance_{it}$	-0.036***	-0.035***	-0.021**	0.046***	-0.005	0.022***	0.052***	0.022***	0.060	-0.001	0.004	0.062***	-0.009
	(0.011)	(0.010)	(0.008)	(0.011)	(0.011)	(0.006)	(0.012)	(0.008)	(0.037)	(0.057)	(0.022)	(0.003)	(0.009)
gov_size_{it}	0.024***	-0.023	-0.051***	-0.086***	0.025	-0.032***	-0.017*	-0.033***	-0.073	-0.049	-0.008	0.017***	
	(0.004)	(0.014)	(0.007)	(0.008)	(0.016)	(0.009)	(0.010)	(0.009)	(0.056)	(0.081)	(0.017)	(0.001)	
gdp_{it}	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)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)		
$population_{it}$	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)	(0.000)	(0.000)	(0.000)	(0.000)			
$trade_{it}$	0.008***	-0.001	0.006***	0.012***	-0.008***	0.007***	0.002**	0.007***	0.014*				
	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.001)	(0.001)	(0.002)	(0.007)				
$unemploy_{it}$	-0.087***	-0.120***	-0.081***	0.122***	-0.032**	0.001	0.032**	0.018					
	(0.008)	(0.007)	(0.009)	(0.013)	(0.015)	(0.013)	(0.014)	(0.014)					
$orient\ right_{it}$	-0.138***	0.827***	0.000	-0.136***	0.480***	-0.112***	0.080*						
	(0.047)	(0.068)	(0.000)	(0.049)	(0.107)	(0.043)	(0.048)						
$orient_left_{it}$	0.000	1.233***	0.125***	0.000	0.609***	0.000							
	(0.000)	(0.112)	(0.046)	(0.000)	(0.122)	(0.000)							
$industry_{it}$	-0.064***	0.074***	0.113***	-0.046***	0.047***								
	(0.007)	(0.010)	(0.007)	(0.009)	(0.012)								
$education_{it}$	-0.008	0.076*	-0.069**	0.017									
	(0.031)	(0.046)	(0.027)	(0.022)									
$patent_{it}$	0.004***	0.002***	0.005***										
	(0.000)	(0.000)	(0.000)										
$ht\ exp_{it}$	0.104***	0.004											
	(0.007)	(0.008)											
$budget_{it}$	0.000												
	(0.000)												
β_o	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.322	3.896	-0.447	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(13.514)	(10.125)	(16.884)	(0.000)	(0.000)
Observations	402	402	406	406	406	408	408	408	408	409	409	409	409
Number of countries	38	38	38	38	38	38	38	38	38	39	39	39	39

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes.

Table A9

Robustness Check. dependent variable: basic research as share of total public R&D spending (b_{it}); revenue decentralization

Explanatory variables	Coefficients, standard errors and statistical significance												
$(dep.var.)_{i,t-1}$	0.968*	0.554	0.908***	0.759***	0.925***	0.909***	0.786***	0.733***	0.847***	0.837***	1.010***	0.911***	0.868***
	(0.565)	(0.368)	(0.098)	(0.019)	(0.017)	(0.061)	(0.058)	(0.185)	(0.153)	(0.114)	(0.103)	(0.034)	(0.036)
dec_{it}	0.631	0.249	-0.906***	0.000	0.000	-0.128	-0.335***	-0.637	-0.539	-0.393	-0.617	-0.037	0.094***
	(1.177)	(0.416)	(0.237)	(0.000)	(0.000)	(0.163)	(0.128)	(0.529)	(0.640)	(0.701)	(0.595)	(0.093)	(0.035)
$imbalance_{it}$	0.597	0.982	-0.037	-0.000	-0.000	0.102	-0.031	0.049	0.374	0.054	-0.363	-0.123	0.025
	(0.680)	(0.728)	(0.208)	(0.000)	(0.000)	(0.155)	(0.174)	(0.672)	(0.400)	(0.349)	(0.427)	(0.176)	(0.115)
gov_size_{it}	0.011	-0.442	0.493***	-0.140***	0.000	0.132**	0.198	0.048	0.064	0.537	-0.170	0.126*	
	(0.802)	(0.710)	(0.156)	(0.051)	(0.000)	(0.064)	(0.130)	(0.357)	(0.516)	(0.578)	(0.226)	(0.067)	
gdp_{it}	-0.000	-0.000	0.000***	0.000***	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)	(0.000)	(0.000)		
$population_{it}$	-0.000	0.000	-0.000*	-0.000	-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)			
$trade_{it}$	-0.062	0.164	-0.088***	-0.033***	-0.015*	-0.008	-0.011	-0.058	-0.011				
	(0.100)	(0.162)	(0.028)	(0.012)	(0.008)	(0.015)	(0.028)	(0.074)	(0.047)				
$unemploy_{it}$	-1.142	0.170	-0.002	-0.054	-0.013	-0.026	-0.077	1.037*					
	(1.473)	(0.389)	(0.170)	(0.039)	(0.048)	(0.152)	(0.306)	(0.607)					
$orient\ right_{it}$	1.704	-12.374	3.110**	1.780***	-0.059	0.836	2.733***						
	(2.906)	(11.646)	(1.311)	(0.333)	(0.437)	(1.179)	(0.645)						
$orient_left_{it}$	1.449	-14.325	-0.394	0.000	0.000	-1.108							
	(6.195)	(11.780)	(1.278)	(0.000)	(0.000)	(1.313)							
$industry_{it}$	-1.501	0.474	0.126	0.543***	0.093**								
	(1.214)	(1.101)	(0.170)	(0.038)	(0.044)								
$education_{it}$	-2.166	-2.370	0.000	0.000									
	(4.673)	(2.334)	(0.000)	(0.000)									
$patent_{it}$	-0.013	0.073	0.006										
	(0.029)	(0.078)	(0.008)										
$ht\ exp_{it}$	0.181	-0.348											
	(0.528)	(0.308)											
$budget_{it}$	-0.021												
	(1.244)												
β_o	62.621	0.000	0.000	0.000	0.000	0.000	0.000	129.569	5.704	-299.952	20.836	0.000	0.000
	(62.408)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(126.120)	(110.047)	(231.982)	(27.357)	(0.000)	(0.000)
Observations	401	401	405	405	405	407	407	407	407	407	407	407	407
Number of countries	38	38	38	38	38	38	38	38	38	38	38	38	38

Coefficients and standard errors estimated through two-step system GMM. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All regressions include time dummies, but their coefficients are not shown for presentation purposes.