Economics Bulletin

Volume 40, Issue 3

Spillover, public investment and innovation: the impact of public investment in R&D on business innovation

Leonardo A. Rocha
Federal Rural University of the Semi-Arid (UFERSA)

Denis Vieira Sarmento
Adelmar Rosado College (FAR)

Carlos Alano S. Almeida
Federal Rural University of the Semi-Arid (UFERSA)

Napiê G.A. Silva
Federal Rural University of the Semi-Arid (UFERSA)

Abstract

This research analyzes the impact of public investment on the relationship "private investment in research versus performance" of the top R&D investors. Taking a recent sample of the top investors, as well as different estimation techniques, the results show that public investments in research contribute to increase the elasticity coefficients of private investments in R&D, either linearly or nonlinearly. In the nonlinear pattern, optimal levels of public policy point to a share of total public investment of around 15.8%, thus maximizing the elasticity coefficient of private investment. Controlling the endogeneity of private investments in R&D, GMM estimates point to an underestimation of the parameters obtained by the OLS technique and robust regression, signaling an increase in the elasticity coefficient of the research. The results of this research converge with other recent studies, highlighting Azoulay et al. (2019) and Kwon and Kwon (2019).

Brazilian National Council for Scientific and Technological Development (CNPq)
Citation: Leonardo A. Rocha and Denis Vieira Sarmento and Carlos Alano S. Almeida and Napiê G.A. Silva, (2020) "Spillover, public investment and innovation: the impact of public investment in R&D on business innovation", *Economics Bulletin*, Volume 40, Issue 3, pages 2344-2360
Contact: Leonardo A. Rocha - leonardoandrocha@yahoo.com.br, Denis Vieira Sarmento - dem.sarmento@gmail.com, Carlos Alano S. Almeida - alano@ufersa.edu.br, Napiê G.A. Silva - napiegalve@yahoo.com.br.
Submitted: August 26, 2019. **Published:** August 24, 2020.

1. INTRODUCTION

The role of efforts in innovation and research externalities in the new growth models are theme of study since the important contributions as Romer (1990), Griliches (1992), Barro and Sala-i-Martin (1992), Aghion and Howitt (1998). In this topic, there is growing interest to investigate the spillover's research on the dynamics of firms, assessing how the targeted policy can influence the incentives for innovation.
In this regard, Azoulay *et al*. (2019, p.117) states:

> *While most studies of innovation focus on a firm's own R&D investments, and more recently on knowledge spillovers between firms (e.g. Bernstein and Nadiri, 1989; Bloom et al., 2013), the impact of public sector research investments has received less attention.*

However, measuring the spillover effect of the research does not consist of a simple task, and many studies have tried to estimate it between firms (see Jaffe 1986, Griffith, Harrison and Reenen 2006, Bloom, Schankerman and Reenen 2013, Rocha *et al*. 2018, and Rocha *et al*. 2019) or between countries (see Park 1995, and Aghion and Jaravel 2015), in order to demonstrate their importance to the technological convergence.

According to Griliches (1992), all research is funded by the public or private sector. This research produces ideas and information that can be applied to new materials or compounds, new organizational techniques and applications in the use of inputs or new ways to design new goods or even services targeted to meet the potential needs of consumers and producers. In each case, the research is influenced that are not only coming from the major investment but are also potentiated by other R&D activities that influence its outcome in the form of externalities or spillovers of research.

On the other hand, some studies have reported the limitations of this effect from public investment, which makes the topic a very current debate. Some research indicates that governments do not hold all the necessary information to select effectively R&D projects for production funding. Thus, public investments in R&D may in a non-targeted attempt exclude private investments as they carry out such projects (crowd-out effect) (Goolsbee 1998; Görg and Strobl 2007). In this pattern of effect, many countries are seeking an optimal level of public R&D investment designed to strengthen the spillover effect as a form of development strategy (Kwon and Kwon 2019).

Within this direction, some important questions motivated the present research: (1) Are public investments in R&D able to improve the private return of research investments? (2) Can different measurement techniques converge on a standard and common understanding of this relationship?

To reply these questions, this relationship was estimated from a sample of the top R&D investors in the world. This sample selection is due to the innovation strategy being more active for this group of firms, minimizing potential costs associated with a sample selection bias (Montresor and Vezzani 2015, Castellani *et al*. 2017, Ciriaci, Grassano and Vezzani 2019). This stems from the different business strategies that condition the return on research from their relative importance to the firm (Coad 2008; 2011).

The study's contributions can be listed below:

1. In the research for a balanced budget of governments, to analyze the impact of specific public investments, such as R&D, is especially important, considering the importance of technical progress for the economic growth (Aghion, Hémous and Kharroubi 2014, Bouakez, Chihi and Normandin 2014).
2. In addition, to investigate the contribution of public investment for innovation firms is a research topic with little attention analyzed by the academy (see Azoulay *et al*., 2019). Therefore, it is essential to study the effectiveness of innovation policy, especially in situations of economic crisis and fiscal austerity, where the resource constraint becomes more severe;
3. Unlike the contributions of Montresor and Vezzani (2015), the R&D investment does not represent a direct input in the production function, but an input of research that increases the productivity of firms within the Total Factor Productivity, following the new generation of endogenous growth models (see Acemoglu and Akcigit 2012, Aghion, Akcigit and Howitt 2013). The absence of this treatment entails a serious bias in the model specification;
4. Sample selection bias may be an important factor of bias in the model estimates (see Greene 2012). Thus, select firms that costumer their efforts on innovation as a relevant strategy to business, demand a very specific selection of investors (see Montresor and Vezzani 2015, Castellani *et al*. 2017, Ciriaci, Grassano and Vezzani 2019);

5. The incentives to internalize public research results represents a non-uniform strategy among companies (see also Acemoglu, Aghion and Zilibotti 2006, Coad 2008; 2011, Akcigit and Kerr 2018). This indicates potential opportunity costs of innovation that are higher in less developed economies (see Aghion and Howitt 2009, Aghion and Jaravel 2015, and Aghion and Festré 2017);
6. Finally, different ways of addressing the effect of public investment converge on the understanding of increasing the impact of private investment on firm performance. This contributes to more robustness in research results.

In the work of the authors Azoulay et al. (2019, p.117), the treatment of the effect of public financing occurs as an explanatory variable in the function of firms' patent stock.

Although public financing is an endogenous variable and properly treated in the instrumental variable technique, the estimated parameter does not directly relate to a measure of the firm's performance, failing to capture an important innovation incentive factor. Although the patent stock represents an important measure of innovative activity, some studies highlight its fragility when not linked to a performance metric, making the evaluation of effort imprecise (GRILICHES, 1992; HALL, 2000; HALL & LERNER, 2009; HALL, MAIRESSE, & MOHNEN, 2010; COAD, 2011; HALL, LOTTI, & MAIRESSE, 2013).

In contrast to this, we estimate the investment elasticity coefficient and assess how sensitive the coefficient becomes to the policy effect. Thus, the incentive structure of firms is better perceived, diagnosing their differences between economies. The elasticity coefficient, in this example, proves to be an important measure of the firm's ownership, based on the investment made. In addition, we highlight the fundamental role of the sample that includes the largest investors in innovation on the planet. These investors account for approximately 90% of all R&D applied in the world. For a better robustness of the research results, different techniques and ways of dealing with the effect of public investment were explored. Although the values of the parameters are not strictly equal between models, we focus more on the convergence of conclusions between models.

2. EMPIRICAL MODEL

2.1. Sample Selection and Data Source

The data used in this article include 2,500 firms according to the information available at The 2016 Edition of the EU Industrial R&D Investment Scoreboard, considering the fiscal year 2015/2016. The report includes an evaluation scenario in relation to investments in R&D of 38 sectors in 45 countries worldwide.

The advantage of this database is that it contemplates the largest innovation investors in the world, accounting for approximately 80-90% of all applied R&D. Thus, in terms of innovation, risks associated with sample selection bias may compromise important research results (Montresor and Vezzani 2015, Castellani *et al*. 2017, Ciriaci, Grassano and Vezzani 2019).

Regarding the data on public spending on R&D, we employed a relative measure (Government Intramural Expenditure on R&D - GOVERD/Gross Domestic Expenditure on R&D - GERD). This information was extracted from the Main Science and Technology Indicators, Volume 2016 by the Organization for Economic Cooperation and Development (OECD). This publication reports a set of indicators reflecting the major efforts made by OECD member countries and seven non-member countries (Argentina, China, Romania, Russian Federation, Singapore, South Africa, Chinese Taipei) in the field of science and technology. The relative measure becomes important in the present research because it deals with the “weight” of public investment or state participation in total investments within each economy.

2.2. Adopted variables

Table 1 describes the selected variables and their source as described in the previous section. The financial variables are reported in euro values (€ million), but were converted into US dollars ($ million) taking currency conversion on the date 31/12 for the year of the data.

Table 1 Description of variables used in the study.

Variables	Description	Source
Sales	*Net sales follow the usual accounting definition of sales, excluding sales taxes and shares of sales of joint ventures & associates* (European Comission, 2016, p.102).	European Comission (2016)
Capex	*Capital expenditure (Capex) is expenditure used by a company to acquire or upgrade physical assets such as equipment, property, industrial buildings. In accounts capital expenditure is added to an*	European Comission (2016)

	asset account (i.e. capitalised), thus increasing the asset's base (European Comission, 2016, p.102).	
R&D	*Research and Development (R&D) investment in the Scoreboard is the cash investment funded by the companies themselves. It excludes R&D undertaken under contract for customers such as governments or other companies. It also excludes the companies' share of any associated company or joint venture R&D investment. Being that disclosed in the annual report and accounts, it is subject to the accounting definitions of R&D. For example, a definition is set out in International Accounting Standard (IAS) 38 "Intangible assets" and is based on the OECD "Frascati" manual* (European Comission, 2016, p.102).	European Comission (2016)
Employees	*Number of employees is the total consolidated average employees or year-end employees if average not stated* (European Comission, 2016, p.102).	European Comission (2016)
Profits	*Operating profit is calculated as profit (or loss) before taxation, plus net interest cost (or minus net interest income) minus government grants, less gains (or plus losses) arising from the sale/disposal of businesses or fixed assets* (European Comission, 2016, p.102).	European Comission (2016)
One-year growth	*Simple growth over the previous year, expressed as a percentage: 1 yr growth = 1OO*((C/8)-1); where C = current year amount, and 8 = previous year amount* (European Comission, 2016, p.102).	European Comission (2016)
Three-year growth	*Compound annual growth over the previous three years, expressed as a percentage: 3 yr growth = 100*(((C/B)1(1/t))-1); where C = current year amount, B = base year amount (where base year = current year - 3), and t = number of time periods (= 3)* (European Comission, 2016, p.102).	European Comission (2016)
Goverd/Gerd	Government Intramural Expenditure on R&D divided by Gross Domestic Expenditure on R&D, as defined in the OECD "Frascati" manual (OECD, 2015). This value is obtained at country-level and used for firms that are of country origin.	Main Science and Technology Indicators, Volume 2016, by OECD.Stat

Source: Own elaboration.
Note: The italic text represents that the text was copied identically to the report, preserving the technical understanding and definition of each variable, and specifying the page for its extraction.

2.3. Econometric model

The estimated model was based on the firm's traditional production function, according to a Cobb-Douglas type function:

$$Y_i = A_i K_i^{\alpha} L_i^{\beta} \quad (1)$$

Y denotes the firms' production output (Sales), L stands for labour (Employees), K for physical capital stocks (Capex) and A represents the technology in use by the firm "i". According to Montresor and Vezzani (2015), this function has been reformulated, adding R&D investments as an additional input to the production function. This treatment, although empirically convincing, does not prove to be theoretically relevant, since endogenous growth models treat R&D investments as an input to the technological parameter (Romer 1990, Aghion and Howitt 1992, and Grossman and Helpman 1994). This human capital, in turn, complements a specific type of technology that demands investments in R&D (Caselli and Coleman 2006). These investments can be represented as a composition between private and public investment (David, Hall and Toole 2000, and Shioji 2001):

$$A_i = A_0 (R\&D_i)^{\gamma} (R\&D_{Gov})^{\delta} \quad (2)$$

According to equation (2), "$R\&D_i$" e "$R\&D_{Gov}$" they represent, respectively, investments in R&D by firms and the public. Reforming the equation for econometric rating, a proxy for public investment was used as the relative value of government R&D spending on total investment (GOVERD / GERD).

From the above reformulation, the econometric model used was divided into two sections, contemplating two alternative ways of treating the effect of public investment on firm performance.

2.3.1. First econometric strategy

Substituting equation (2) into (1) and applying logarithm, the estimated equation can be represented as:
EM.1:

$$log(Y_i) = \beta_0 + \beta_1 log(K_i) + \beta_2 log(L_i) + \beta_3 log(R\&D_i) + \beta_4 \left(\frac{GOVERD}{GERD}\right) + \varepsilon_i$$

To capture the spillover-effect of public investment, the cross-effect between investments was added to the model. Thus, the partial effect of private investment depends on an additional component (GOVERD/GERD) that reinforces its final effect on firm performance.

The parameters of the variables, except for the variable $\left(\frac{GOVERD}{GERD}\right)$, represent coefficients of elasticity and $(\varepsilon_i \sim N(0, \sigma_\varepsilon^2))$ the stochastic disturbance of the model.

EM.2:

$$log(Y_i) = \beta_0 + \beta_1 log(K_i) + \beta_2 log(L_i) + \beta_3 log(R\&D_i) + \beta_4 \left(\frac{GOVERD}{GERD}\right) + \beta_5 \left[log(R\&D_i) \cdot \left(\frac{GOVERD}{GERD}\right)\right] + \varepsilon_i$$

As the variables were transformed into log, the estimated parameters represent elasticity coefficients of each variable: $\epsilon_i^{R\&D} \equiv \frac{\partial log(Y_i)}{\partial log(R\&D_i)} = \beta_3 + \beta_5 \left(\frac{GOVERD}{GERD}\right)$ (3)

According to equation (3), the R&D elasticity coefficient of investments can be represented as a linear and increasing function of the public investment component. Therefore, in economies with a greater share of public investment than total investment, the greater the reinforcement of private investment in firm performance.

A variation of equation ME.2 is to include a nonlinear effect of public investment. Thus, the final effect of the R&D elasticity coefficient of investments is nonlinearly affected by public investment. To include this final effect in the research elasticity coefficient, in equation ME.2 the quadratic component of public investments interacted with private investment is added, as shown below:

EM.3:

$$log(Y_i) = \beta_0 + \beta_1 log(K_i) + \beta_2 log(L_i) + \beta_3 log(R\&D_i) + \beta_4 \left(\frac{GOVERD}{GERD}\right) + \beta_5 \left[log(R\&D_i) \cdot \left(\frac{GOVERD}{GERD}\right)\right] + \beta_6 \left(\frac{GOVERD}{GERD}\right)^2 + \beta_7 \left[log(R\&D_i) \cdot \left(\frac{GOVERD}{GERD}\right)^2\right] + \varepsilon_i$$

The partial elasticity of R&D is obtained by partial derivative:

$$\epsilon_i^{R\&D} \equiv \frac{\partial log(Y_i)}{\partial log(R\&D_i)} = \beta_3 + \beta_5 \left(\frac{GOVERD}{GERD}\right) + \beta_7 \left(\frac{GOVERD}{GERD}\right)^2 \quad (4)$$

2.3.2. Second econometric strategy

An alternative approach to the effect of public research investment is to treat the demand of private investment as an endogenous function of public effort in research.

As David, Hall and Toole (2000), public research funding complements and encourages significant private spending in R&D, although private investment has been carried out for other purposes. Government agencies constantly sponsor research projects, the orientation of discoveries that sometimes cannot be financed privately, without taking a financial purpose, for example, in military technology areas and public health. Although the initial funding is from public sources, in many situations, the financed project may meet later to a private orientation for further research. Thus, firms end up benefiting directly or indirectly from public research (Segerstrom 2000, Shioji 2001, and Coccia 2010; 2011).

Following the understanding of David, Hall and Toole (2000) and Coccia (2010; 2011), private investment in R&D are conditioned by major public investments in research, derived from innovation policy:

$$R\&D_i = \vartheta(R\&D_{Gov}; X_i) + \eta_i \quad (4)$$

According to equation (4), private investment is endogenously conditioned by public investments, contributing to increase the effectiveness of the investment applied.

However, other factors in firm size also contribute to decision making on research investments. Following the endogenous Schumpeterian growth models, in particular Acemoglu, Aghion and Zilibotti (2006), Aghion and Griffith (2006), Aghion and Howitt (2009), Aghion, Howitt and Prantl (2015) and Aghion and Festré (2017), in firm equilibrium conditions the appropriate profits drive a significant portion of R&D investments.

In this case, equation (4) now includes profits (π_i) as another conditioning factor for firms' investment in research: $R\&D_i = \vartheta(R\&D_{Gov}; \pi_i) + \eta_i$ (5)

Considering the endogeneity of private investment in research, EM.2 equation can be reformulated as:

EM.4

$$log(Y_i) = \beta_0 + \beta_1 log(K_i) + \beta_2 log(L_i) + \beta_3 log(R\&D_i) + \varepsilon_i$$

$$log(R\&D_i) = \alpha_0 + \alpha_1\left(\frac{GOVERD}{GERD}\right) + \alpha_2\left(\frac{GOVERD}{GERD}\right)^2 + \alpha_3 log(\pi_i) + \eta_i$$

The use of profit as an instrument consists of the literature of endogenous growth, especially in the Shumpeterian approach of Aghion and Howitt (1992; 1998; 2009). According to Aghion and Howitt (2009), the innovative firm seeks to optimize the expected consumption by maximizing its profits. Under the firm's equilibrium conditions, the reward for the innovative firm consists of the profit to be appropriated due to the success of the innovation in the market. In other words, investment in research is guided by the result of innovation, which consequently becomes a function of the firm's profits. "*Thus, it should lead to more intense research, as it raises the profit that accrues to a successful innovator. This in turn should result in higher growth.*" (Aghion and Howitt, 2009, pp.92). In addition, Hu (2001), in an empirical study on the topic, states that there is substantial information asymmetry throughout the execution of R&D projects. In addition, external financing for investments in R&D is relatively expensive, requiring part of the firms' own funds. An important measure of the availability of own funds is cash flow. In the absence of this measure, profits are an important proxy measure for domestic funds.

In order to compare divergences in estimates, according to different instruments at firm-level, the following instruments were adopted: profit with one year lag ($log(\pi_{it-1})$), profit with three years lag ($log(\pi_{it-3})$), profits one-year growth ($g(\pi_{it-1})$), and profits three-years growth ($g(\pi_{it-3})$). This procedure aims to control potential effects of endogeneity in the current period's profits.

The next section deals with the estimation techniques for each econometric approach, presenting the parameters efficiency and consistency conditions, according to the different estimation methods.

2.4. Estimation methods and robustness

Equations EM.2 and ME.3 are estimated using the standard Ordinary Least Squares (OLS) technique. In the presence of heteroscedasticity, the estimation efficiency requirements are violated, leading to a bias in confidence intervals. In the presence of heteroscedasticity, White's (1980) estimator will be adopted to correct the failure of the statistical assumption to the model.

A relatively common problem in micro-level data sampling, especially in this case with financial series, it is the presence of outliers that distort the estimates which leads to a serious bias in the estimated parameters. To circumvent this problem and obtain consistent parameter estimates, the robust regression technique was applied. This technique becomes appropriate both in the presence of discrepant data in the sample and in the absence of normal error distribution, proving to be efficient (Verardi and Croux 2009, and Hamilton 2013).

In equation EM.4, the OLS technique does not adequately address the endogeneity observed in the variable "R&D investment". The endogenous effect of investment is best addressed through the Generalized Method of Moments (GMM) approach. This technique is more efficient in the presence of heteroscedasticity (Bond, Hoeffler and Temple 2001, Baum, Schaffer and Stillman 2003, and Hsiao and Zhang 2015).

3. ANALYSIS OF RESULTS

3.1. Sample descriptive analysis

Table 2 presents the statistical coefficients of mean, standard deviation, minimum and maximum values, in relation to the adopted variables.

Table 2 Descriptive statistics of variables used in this study.

Variable	Obs	Mean	Std. Dev.	Min	Max
Sales	2,500	8,110.00*	22,900	0.10500*	294,000.00*
Employees	2,500	23,326	52,210	12	610,076
Capex	2,500	558.00*	2,250	0.018769*	32,500.00*
R&D	2,500	373.00*	1,100	22.40*	14,300.00*
Profits	2,500	638.00*	2,460	-8600*	68,700.00*
Goverd/Gerd	2,500	0.1070	0.0382	0.0159	0.4906

Source: Own elaboration.
Note: (*) Values are in $ 1 million.

According to the sample, average investment in R&D was $ 373 million, with the largest investing firm being Volkswagen with $ 14.2 billion, followed by Samsung with $ 13.1 billion and Intel, Microsoft and Alphabet with approximately $ 11.6 billion. The company that least invested in the sample represented the French Radiall with $ 22.4 million.

Average sales were much higher than research investments, with $ 8.1 billion. The same companies had sales performance of: $ 223.9 billion (Volkswagen), $ 165.1 billion (Samsung), $ 53.4 billion (Intel) and $ 304.4 million (Radiall). Considering the top performers in sales, China's China Communications Construction ($ 296.3 billion), US HP ($ 256.35 billion), Japan's Fujitsu ($ 255.5 billion) and Nvidia ($ 250.3 billion).

With regard to investment capital assets (capex), the sample average stood at around $ 558 million. Companies with higher volume in these investments represented the Japanese Toyota Motors and American HP with approximately $ 32 billion. These same companies invested in R&D equivalent to $ 8.45 billion (Toyota Motors) and $ 3.4 billion (HP), as well as a result of sales of approximately $ 227.3 billion (Toyota Motors) and $ 256.35 billion (HP).

Table 3 presents the correlation matrix with the model variables. Except for the Goverd/Gerd correlation between log(sales) and log(emp), all other coefficients showed signs of statistical significance.

Table 3 Correlation Matrix.

	log(profits)	log(sales)	log(emp)	log(capex)	log(R&D)	Goverd/Gerd
log(profit)	1					
log(sales)	0.8470***	1				
log(emp)	0.7340***	0,9116***	1			
log(capex)	0.7786***	0,8601***	0,8696***	1		
log(R&D)	0.6561***	0,5735***	0,5564***	0,5877***	1	
Goverd/Gerd	-0.0416*	-0,0295	-0,0341	-0,0494**	-0,0404**	1

Source: Own elaboration.

Note: *** p<0.01, ** p<0.05, * p<0.1. The hypotheses of the correlation test can be presented as $H_0: \rho = 0 \therefore H_a: \rho \neq 0$.

3.2. Econometric result

3.2.1. First strategy

Table 4 shows the results of the estimates of the econometric model, reporting the elasticity of the production function coefficients.

According to the estimates, the first column reports the results from the traditional technique OLS. The estimates obtained for all variables showed signs of high statistical significance (at 1%).

Of all the parameters, the labor elasticity coefficient was higher, so that an increase in input stock implies the increasing in sales of 0.75%. In relation to investments in capital goods, the result was 0.30%, so that an increase in these investments implies an average increase of 0.30% in sales. For investments in R&D, the value was found to be less than and equivalent to 0.07%, so a proportional increase in these investments implies an average sales growth of 0.07%.

Table 4 Regression results.

VARIABLES	(1) OLS	(2) Robust Regression
log(emp)	0.750***	0.579***
	(0.0358)	(0.0132)
log(capex)	0.307***	0.324***
	(0.0253)	(0.0119)
log(R&D)	0.0740***	0.137***
	(0.0176)	(0.0119)
Constant	7.705***	7.824***
	(0.278)	(0.191)

R2	0.8594	0.917
R2-Adj	0.8592	-
Test for Heteroskedasticity (chi2)	161.27***	-
Test for Heter. (p-value)	0.000	-
F stat	2305***	6786***
F stat (p-value)	0.000	0.000

Source: Own elaboration.
Note: *** p<0.01, ** p<0.05, * p<0.1 Standard errors in parentheses. Standard error estimates were recalculated using White's (1980) estimator.

Compared with the column (2) in the same Table, the results obtained by the "robust regression" technique shows a clear bias of the estimates obtained by the traditional technique OLS. First, the coefficient of labor elasticity showed a significant reduction, from 0.75 to 0.58 (a reduction of approximately 23%). This indicates the bias provided by the sample's outlier which considerably influence the values of the estimates, overestimating the coefficient of elasticity. Instead, the capital and research elasticity coefficients had increased values after the alternative technique. Increased elasticity of the capital proved to be smooth, rising from 0.31% to 0.32%. In the research coefficient of elasticity, the variation showed the highest, indicating an increase in approximately 85% after the technical parameter 'robust regression' (from 0.07% to 0.137%), almost doubling the parameter value.

Table 5 now considers the expansion of the traditional model by considering the "spillover-effect" of public research investments.

In column (1), the obtained results indicate a relative stability of the parameters after the inclusion of the variable "Goverd/Gerd". The estimated parameters showed a slight deviation from the previous table, except for the log variable (R&D), whose estimate showed a slight decrease of 10% (from 0.074 to 0.0666). The parameter of the interacted variable [log (R&D)*(Goverd/Gerd)] showed an expected and positive sign, but not significant at the maximum level of 10% (the survey elasticity coefficient was also not significant at 10%).

In column (2), the parameter estimates showed values close to the previous table, with the exception of the research coefficient of elasticity, reducing from 0.137% to 0.071%. The approximation of the estimated value for the magnitude of the parameter obtained in the column (1) of the above table reveals the deviation of the calculated parameters may be influenced by the effect of public investment-spillover. Consequently, growth in the parameter of approximately 85% after the technical 'robust regression' in relation to the OLS in the table above, suggests that the influence of public investment can enhance the effect of private investment in research, particularly in economies where public investment is more present.

Comparing the different parameter values of the [log(R&D)*(Goverd/Gerd)] variable by estimation technique, indicates that the outlier's effect in the sample tends to underestimate the spillover effect of public research investment. The estimate from column (1) indicates an increase from 0.0652% to 0.574%, representing an increase of approximately 780% as we control the effect of outliers in the sample.

Table 5 Regression results.

VARIABLES	(1) OLS	(2) Robust Regression
log(emp)	0.745***	0.576***
	(0.0401)	(0.0136)
log(capex)	0.312***	0.332***
	(0.0439)	(0.0123)
log(R&D)	0.0666	0.0707**
	(0.0407)	(0.0358)
log(R&D)*(Goverd/Gerd)	0.0652	0.574*
	(0.3291)	(0.314)
(Goverd/Gerd)	-0.726	-10.70*
	(6.0601)	(5.719)
Constant	7.737***	8.954***
	(0.6066)	(0.640)

R^2	0.860	0.916
R^2-Adj	0.860	-
Test for Heteroskedasticity (chi2)	911.83***	-
Test for Heter. (p-value)	0.000	-
F stat	2,144***	3,829***
F stat (p-value)	0.000	0.000

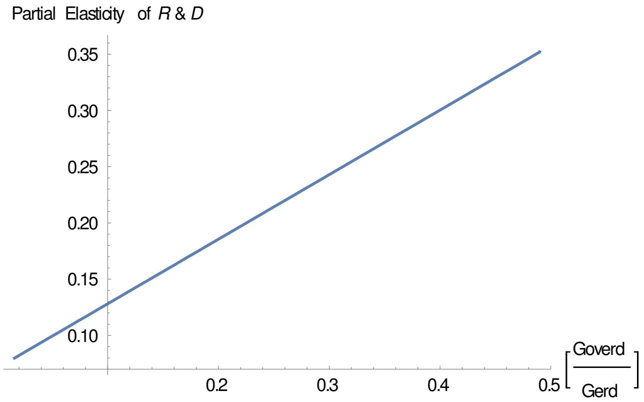
Source: Own elaboration.
Note: *** p<0.01, ** p<0.05, * p<0.1 Standard errors in parentheses. Standard error estimates were recalculated using White's (1980) estimator.

The final effect of the research elasticity coefficient is defined by the partial derivative:

$$\hat{\epsilon}_i^{R\&D} \equiv \frac{\partial log(Y)}{\partial \log(R\&D)} = 0.0707 + 0.574 * \left(\frac{Goverd}{Gerd}\right) \qquad (6)$$

Graph 1 shows the evolution of the parameter to different values along the minimum and maximum values in the variable sample (Goverd/Gerd).

Graph 1 Effects on R&D elasticity.



Source: Own elaboration.
Note: Simulation performed from Robust Regression results.

Graph 1 above shows the convergence of values for the survey elasticity coefficient as those variable values (Goverd/Gerd) increase. This suggests that the 'weight' of public investment has a direct effect on private investment in research, leveraging the innovation effort.

The above results indicate that firms in countries with a higher share of public spending on research in relation to total investments, manage higher elasticity coefficients of their private investments. The illustrative effect of the results, the minimum amount of public resources as table information 2 was GOVERD/Gerd = 0.0159. This signals to a research average coefficient of elasticity of approximately 0.08%. For the largest observed value GOVERD/Gerd = 0:49, the ratio rose to 0.35%.

3.2.2. Nonlinear effects

Table 6 presents the estimates considering the nonlinear effect of public investments in research (with the addition of the quadratic component of the Goverd/Gerd variable).

Table 6 Regression results.

VARIABLES	(1) OLS	(2) Robust Regression
log(emp)	0.746***	0.577***
	(0.0368)	(0.0136)
log(capex)	0.311***	0.331***
	(0.0260)	(0.0123)
log(R&D)	-0.0123	-0.0231
	(0.0714)	(0.0588)
log(R&D)*(Goverd/Gerd)	1.580	2.336**
	(1.136)	(0.948)

(Goverd/Gerd)	-28.12	-43.58**
	(21.08)	(17.18)
log(R&D)*[(Goverd/Gerd)^2]	-6.696	-7.589*
	(4.730)	(3.955)
(Goverd/Gerd)^2	120.8	140.6**
	(85.86)	(71.35)
Constant	9.171***	10.72***
	(1.361)	(1.064)
R^2	0.860	0.917
R^2-Adj	0.860	0.916
Test for Heteroskedasticity (chi2)	153.58***	
Test for Heter. (p-value)	0.000	
F stat	984.2	2741.95
F stat (p-value)	0.000	0.000
$^{\delta}$ Optimal Level of Goverd/Gerd	0.1180	0.1539

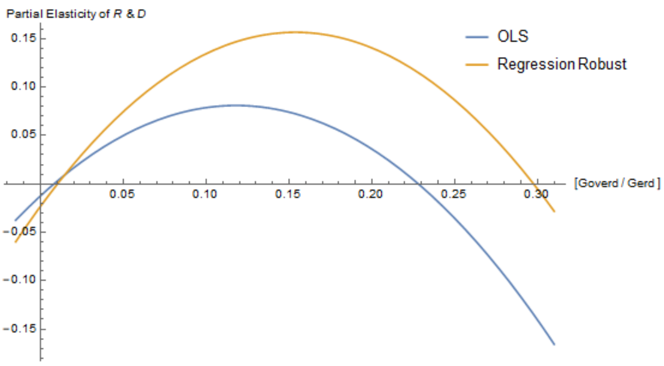
Source: Own elaboration.
Note: *** p<0.01, ** p<0.05, * p<0.1 Standard errors in parentheses. Standard error estimates were recalculated using White's (1980) estimator. "δ" – The optimal level of the variable (Goverd/Gerd) represents the value that maximizes the partial elasticity of private R&D.

In the OLS estimates (column (1)) only the parameters of the log (emp) and log (capex) variables showed signs of statistical significance (at 1% level). The labor and Capex elasticity coefficients presented values, respectively, of 0.75% and 0.31%, similar to the estimates of Table 5. The R&D elasticity coefficient of investments presented negative values, although not significant. The Goverd/Gerd variable in its linear form had a negative sign parameter and the R&D interaction parameter a positive value. This same relationship pattern was also observed in the quadratic form, although with no statistical significance.

In column (2), the robust regression technique converged the estimates of labor and Capex elasticity coefficients to values similar to Table 5 (0.58% and 0.33% respectively). The research elasticity coefficient (R&D) was negative, although not significant. In addition, OLS estimates showed an underestimation pattern in relation to robust regression. The nonlinear relationship of the Goverd/Gerd variable demonstrates a downward concavity polynomial function, indicating the existence of a maximum in the function. By estimating the maximum value of the function, the R&D elasticity coefficient of private investments can be optimized to the values of 11.80% and 15.40% in columns (1) and (2), respectively. There is also an underestimation of the share of public investment in the total composition for OLS estimates. Controlling the effect of outlier's in the sample, the ratio increases, generating a bias in the result when we neglect their influence on the model.

Graph 2 summarizes this relationship by showing the relationship between public and private investment in R&D. The nonlinear relationship signals equilibrium conditions that imply optimizing the private return on investment from a public policy.

Graph 2 Effects on R&D elasticity.



Source: Own elaboration.
Note: Simulation performed from Robust Regression results.

3.2.3. Second strategy

Table 7 presents the regression results according to the Generalized Moments Method.

Table 7 Regression results.

VARIABLES	(1) GMM
log(emp)	0.322***
	(0.0321)
log(capex)	0.169***
	(0.0306)
log(R&D)	0.764***
	(0.0622)
Constant	1.480**
	(0.716)
F	1245***
F (p-value)	0.000
Kleibergen-Paap rk LM statistic (chi2)	125.6***
Kleibergen-Paap rk LM statistic (p-value)	0.000
Endogeneity test (chi2)	160.5***
Endogeneity test (p-value)	0.000
Hansen J statistic (chi2)	2.677
Hansen J statistic (p-value)	0.262

Source: Own elaboration.

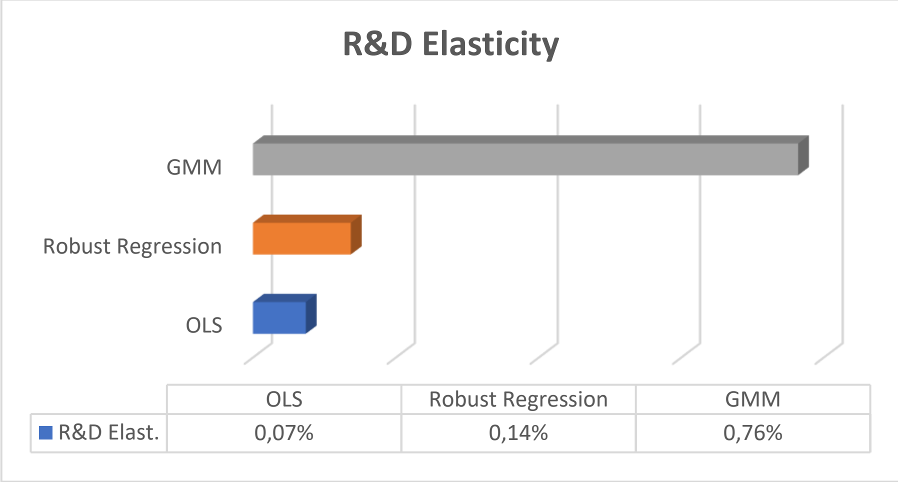
Note: *** p<0.01, ** p<0.05, * p<0.1 Standard errors in parentheses.

The results show a reversal in the parameter estimates, indicating a growing effect for the research elasticity coefficient according to different estimation techniques. All parameter estimates revealed signs of statistical significance (between 1% and 5%). In Table 4, labor elasticity coefficient estimates showed values of 0.75% (OLS) and 0.58% (robust regression), well above the GMM estimate of 0.32%. Regarding the elasticity coefficient of investment in capital goods, the estimates were 0.31% (OLS) and 0.32% (robust regression), against 0.17% (GMM). Comparing to the survey elasticity coefficients, the estimates were 0.074% (OLS) and 0.137% (robust regression) versus 0.764% (GMM). These values indicate that an absence of control in the estimation technique tends to underestimate the elasticity coefficient.

The statistics from Kleibergen and Paap (2006) indicate that the instruments are relevant and thus help to significantly explain the endogenous variable (R&D). The J-Hansen test indicates not rejecting the null hypothesis of instruments not correlated with stochastic perturbation, pointing to the validity of the instruments. The endogeneity test demonstrated to reject the null hypothesis, indicating that the differences between the estimates obtained by different techniques are systematic and the GMM technique presents more consistent results to the parameters.

Graph 3 summarizes the trend of the parameters according to the different estimation techniques. Controlling the observed endogeneity, the other techniques underestimate the research elasticity coefficient.

Graph 3 Comparing the investment elasticity coefficients in R&D.



Source: Own elaboration.

The different estimation techniques point to a convergent result that public investments in R&D have an effect of increasing the research result from private investments.

3.2.3.1 Instruments with Growth and Lagged Variables

Table 8 presents a comparison of the GMM technique from different instruments, taking profits as lagged variables (in level and growth):

Table 8 Regression results.

VARIABLES	(1) GMM	(2) GMM	(3) GMM	(4) GMM
log(emp)	0.870***	0.743***	0.793***	0.827***
	(0.0498)	(0.0811)	(0.0505)	(0.0382)
log(capex)	-0.111***	-0.235***	-0.168***	-0.107***
	(0.0374)	(0.0707)	(0.0413)	(0.0287)
log(R&D)	0.618***	1.098***	0.898***	0.658***
	(0.126)	(0.252)	(0.161)	(0.102)
Constant	4.195***	-1.268	0.763	3.767***
	(1.401)	(2.867)	(1.917)	(1.196)
F	454.5***	244.7***	578.1***	720.0***
F (p-value)	0.0000	0.0000	0.0000	0.0000
Kleibergen-Paap rk LM statistic (chi2)	39.04***	28.10***	42.93***	40.26***
Kleibergen-Paap rk LM statistic (p-value)	0.0000	0.0000	0.0000	0.0000
Endogeneity test (chi2)	15.50***	40.31***	36.43***	24.10***
Endogeneity test (p-value)	0.0001	0.0000	0.0000	0.0000
Hansen J statistic (chi2)	26.76***	8.740**	14.89***	45.47***
Hansen J statistic (p-value)	0.0000	0.0127	0.000584	0.0000
- Instruments (growth and lagged variables)	profit with one year lag	profit with three years lag	profits one-year growth	profits three-years growth

Source: Own elaboration.
Note: *** p<0.01, ** p<0.05, * p<0.1 Standard errors in parentheses.

Comparing the results of Table 8 with Table 7, the expected sign of the log variable (capex) proved to be negative, but significant at 1% in all columns. The estimates of the elasticity coefficients of work showed higher and significant values at 1%. Regarding the research elasticity coefficient, the results are convergent with the previous table, showing higher values after controlling for endogeneity.

When comparing lagged instruments (log(profits)), a greater time lag implied in increasing the research elasticity coefficient, an inverse pattern when comparing with growth rates. The instruments presented a strong correlation with the endogenous variable, but the hypothesis of no correlation with the stochastic disturbance (rejection of the null hypothesis in the Hansen J statistic) was rejected - column (2) did not reject the null hypothesis of J-Hansen test when 1% level.

3.3. Discussion of results

The research results show that public investments in research have the effect of increasing the elasticity of private investments in innovation, considering the different econometric methodologies. Using a microdata-level sample, Kwon and Kwon (2019) used a database from South Korea's National Science and Technology Information Service (NTIS), incorporating information on resource-financed research and development projects since 2002.

Adopting a methodological proposal similar to the present research, the authors estimated the interacted effect of public investment with the private investment of the R&D project. The dependent variable of the regression model implied a Research Performance Index that covered research metrics according to the number of patents registered, published articles (national and international), SCI papers, among other measures aggregated in an overall index. As a result, the interacting effect of public investment revealed a direct contribution of public policy to the "R&D project x private investment in R&D" relationship. Thus, larger public investments contribute to increase the effect of private investment on the research performance index in a linear way.

In specific biotechnology and pharmaceutical sectors, targeting public investment in private innovative activity has also shown recent and positive results. According to Azoulay *et al.* (2019), funding through subsidies directed to scientific research has shown a clear positive and significant effect on patenting by pharmaceutical and biotechnology companies. The study results show that an increase of approximately $ 10 million in funding from the institutes through public resources contributes, on average, to a 2.7 increase in patent registration. This pattern is also observed in the positive effect on patent value through different valuation techniques. Estimates indicate that the same $ 10 million of public funding contributes on average to an approximate $ 30.2 million in the firm's market value. An increasing value compared to data from previous years, since estimates of the same sector had a value of $ 11.2 million per registered patent (Bessen 2009).

Another particular way of looking at this relationship is the contribution of Maietta (2015), by analyzing the determinants of R&D collaboration from the university-firm relationship and its impact on innovation, from a case study for the low-income industry technology. Universities play a key role in training highly qualified human resources, especially when such resources are complemented with technology (Caselli and Coleman 2006), so that firms near universities tend to benefit by stimulating the process of innovation. In addition, geographic proximity plays a key role in university-industry collaboration, favoring the construction of industrial clusters as firms advance technologically (D'Este, Iammarino and Guy 2013). Evidence in certain economies also demonstrates this positive relationship (Callejón and García-Quevedo 2005, and Afcha and López 2014). These divergences point to the need for further discussion, especially when considering potential differences between firms, whether in terms of incentives for innovation, sensitivity to cash fluctuations, different types of innovation based on the size distribution of firms, among others factors (Akcigit and Kerr 2018). Different strategies condition the results between firms, attributing distortions that directly reflect the result of innovation (Coad 2011).

In conditions below the optimum level, the firm's technological trajectory can be greatly affected, especially considering the firms furthest from the technological frontier. According to David, Hall and Toole (2000, p.505), "(…) publicly subsidized R&D activity can yield learning and training effects that acquaint the enterprise with the latest advances in scientific and engineering knowledge, and so enhance its efficiency in conducting its own R&D programs." When public investment is limited, a part of the firm's technological trajectory is also limited.

According to Görg and Strobl (2007), a public resource destined to innovation, in many situations, seeks to reduce private costs, transforming initially non-profit projects into profitable projects. In other situations, public resources seek to accelerate the completion of projects in progress, encouraging in each case private R&D activity. In some cases, the training of highly qualified human resources depends on public resources in many countries, in the form of scholarships, public universities, etc.; whose fiscal policy orientation may compromise its expansion (AGHION, HÉMOUS, & KHARROUBI, 2014).

However, in some situations, substantial fiscal adjustments have been associated with an increase in growth in many economies (PEROTTI, 1999). In this case, more developed countries and located closer to the technological frontier enjoy a competitive environment that "softens" the negative externalities of fiscal austerity (AGHION, HÉMOUS, & KHARROUBI, 2014).

According to Aghion, Hémous and Kharroubi (2014), a possible explanation for this is the orientation of the more countercyclical fiscal policy to have a positive effect on growth, since it provides incentives to seek innovative investments in the long term. In this case, understanding the conditions of the countercyclical fiscal policy becomes important for the analysis, especially in the institutional characteristics or arrangements that contribute to promote or prevent. These characteristics are distinct between economies and potential political conflicts can help to understand such differences between nations.

Similar results, based on the instrumental variable technique, point to a convergence in understanding. According to Hu (2001), in the absence of endogenous control over research investments, the impact of public investment is underestimated, so that the traditional OLS technique fails to capture accurately. Table 9 presents a comparison between similar studies, according to the different techniques employed.

Table 9 Comparison between similar studies.

Author	Data type	Dependent variable (private R&D)	Independent variable (Public R&D)	Controls Variables	Method	Final effect of government R&D
Howe and McFetridge (1976)	Firm panel within industry	U$ private R&D expenditure	U$ government R&D grants	Size, profit, deprec, HHI	weighted OLS	mixed (positive and negative)
Antonelli (1989)	Firm cross section within industry	log(private R&D)	log(government R&D)	Size, profit, share for sales	OLS	positive
Lichtenberg (1988)	Panel across industry	U$ Private R&D expenditure	U$ Government-financed R&D	Year dummies, size, sales to government	Fixed Effect, OLS, IV	positive (FE), negative (IV)
Toivanen and Niininen (1998)	Panel across industry	U$ Private R&D expenditure	U$ Government-financed R&D	Investment, cash flow, interest rate	IV	negative for large firms
Wallsten (2000)	Firm panel within industry	U$ Private R&D expenditure	U$ Government R&D subsidy	Age, employment, patents, R&D spending (lagged two period)	OLS, IV	negative (IV)
Hu (2001)	Firm cross section	U$ Private R&D expenditure	U$ government R&D grant	total profit, sales, industry dummies, ownership dummies	OLS, IV	positive
Lach (2002)	Firm panel within industry	log(private R&D)	log(government R&D subsidy)	Employment, sales	OLS, Fixed Effects	mixed (positive and negative)

Source: Adapted from David, Hall and Toole (2000) and expanded to more authors.

4. CONCLUDING REMARKS

The present study analyzed the impact of public investments on the "private investment in R&D *versus* performance" relationship. From a sample of the largest innovation investors in the world and different econometric techniques, the study results show that the participation of public investments has a positive effect on increasing the private investments elasticity coefficient in research.

The first results of the econometric exercise indicate a linear, positive and significant effect of the relationship. Comparing the OLS and robust regression techniques, the result points to underestimations and non-significant relationships from the first technique. Proper control of the influence of outlier's in the sample directly impacts the parameters, leading to a bias of non-influence of public policy on the relationship between model variables.

Nonlinear results were also observed and point to a balance in the relationship between public and private investment. Estimates between the different techniques point to an underestimation of the OLS result. The robust regression technique indicates to the same effect, but with significant results and indicating that the equilibrium value of public investment becomes larger.

Controlling the endogeneity of private investment in R&D, the results indicate that OLS and robust regression estimates point to a bias in the investments in R&D elasticity coefficient, underestimating the model parameters in relation to the GMM technique. Comparing the estimate of the R&D elasticity coefficient between the techniques, the result for GMM points to a bias of approximately 5 times greater than robust regression and 11 times greater than OLS. In addition, the GMM technique shows a trend reversal between estimates, making the research elasticity coefficient superior to labor and capital goods investments (capex).

In addition, sample selection problems are relatively common and occur in numerous applications in econometrics (PUHANI, 2000). Although, the sample selection in accordance with the Top investors in innovation drastically reduces the problem involved, measures such as the Heckman selection, can better isolate the effect of public investment and more accurately understand its effect on private investment. Among the limitations presented, there is a wide field to explore the theme in future research.

The results derived from the research converge with other studies, especially the contributions of Azoulay et al. (2019), Kwon and Kwon (2019) and David, Hall and Toole (2000). Although the research is consistent with recent findings, studies aimed at sample expansion or even in particular economies are needed to make the highlighted conclusions even more effective.

Recent researches on the theory of endogenous growth, in particular Aghion and Howitt (1992; 1998; 2009), highlight the role of "distance to the technological frontier" in innovation and the incentive economy structure. However, the empirical structure of the present study was not directed towards this treatment, however its highlight becomes relevant for the debate and the citation of the journal.

In addition, issues related to efficiency, or even "distance to the technological frontier" are important factors that can affect the result of public investment in different economies. Firms that work closer to the technological frontier present a more distinctive structure of their innovative activity in relation to the more distant firms, conditioning public investment absorbed. In this case, possible aspects, such as the absorptive capacity of firms, can enhance the effect of the policy, explaining possible gaps in policy results between different economies. This highlight is important to compare with the results of the present study.

REFERENCES

Acemoglu, D., and Akcigit, U. (2012). "Intellectual Property Rights Policy, Competition and Innovation." *Journal of the European Economic Association*, **10**(1), 1–42.

Acemoglu, D., Aghion, P., and Zilibotti, F. (2006). "Distance to Frontier, Selection and Economic Growth." *Journal of the European Economic Association*, **4**(1), 37–74.

Afcha, S., and López, G. (2014). "Public funding of R&D and its effect on the composition of business R&D expenditure." *BRQ Business Research Quarterly*, **17**, pp. 22-30.

Aghion, P., and Festré, A. (2017). "Schumpeterian growth theory, Schumpeter, and growth policy design." *Journal of Evolutionary Economics*, **27**(1), 25–42.

Aghion, P., and Griffith, R. (2006). *Competition and Growth*. Cambridge, MA: MIT Press.

Aghion, P., and Howitt, P. (1992). "A Model of Growth Through Creative Destruction." *Econometrica*, **60**(2), 323-351.

Aghion, P., and Howitt, P. (1998). *Endogenous Growth Theory*. Cambridge, MA: MIT Press.

Aghion, P., and Howitt, P. (2009). *The Economics of Growth*. Cambridge, Massachusetts: The MIT Press.

Aghion, P., and Jaravel, X. (2015). "Knowledge Spillovers, Innovation and Growth." *The Economic Journal*, **125**(583), 533-545.

Aghion, P., Akcigit, U., and Howitt, P. (2013). "What Do We Learn From Schumpeterian Growth Theory?" In P. Aghion, and S. Durlauf, *Handbook of Economic Growth* (Vol. 2A, pp. 515-563). North Holland: Elsevier.

Aghion, P., Askenazy, P., Cette, G., Berman, N., and Eymard, L. (2012). "Credit constraints and the cyclicality of R&D investment: evidence from France." *Journal of the European Economic Association*, **10**(5), 1001–1024.

Aghion, P., Hémous, D., and Kharroubi, E. (2014). "Cyclical fiscal policy, credit constraints, and industry growth." *Journal of Monetary Economics*, **64**, 41-58.

Aghion, P., Howitt, P., and Prantl, S. (2015). "Patent rights, product market reforms, and innovation." *Journal of Economic Growth*, **20**(3), 223-262.

Akcigit, U., and Kerr, W. (2018). "Growth through Heterogeneous Innovations." *Journal of Political Economy*, **126**(4), pp. 1374–1443.

Antonelli, C. (1989). A failure-inducement model of research and development expenditure. *Journal of Economic Behavior and Organization*, **12**, 159–180.

Azoulay, P., Zivin, J., Li, D., and Sampat, B. (2019). "Public R&D Investments and Private-sector Patenting: Evidence from NIH Funding Rules." *Review of Economic Studies*, **86**(1), pp. 117–152.

Barro, R., and Sala-I-Martin, X. (1992). "Convergence." *The Journal of Political Economy*, **100**(2), 223-251.

Baum, C., Schaffer, M., and Stillman, S. (2003). "Instrumental variables and GMM: Estimation and testing." *Stata Journal*, **3**(1), 1-31.

Bessen, J. (2009). "Estimates of Patent Rents from Firm Market Value." *Research Policy*, **38**(10), pp. 1604–1616.

Blank, D., & Stigler, G. (1957). *The Demand and Supply of Scientific Personnel*. New York: National Bureau of Economic Research (NBER Books).

Bloom, N., Schankerman, M., and Van Reenen, J. (2013). "Identifying Technology Spillovers and Product." *Econometrica*, **81**, pp. 1347–1393.

Bond, S., Hoeffler, A., and Temple, J. (2001). GMM Estimation of Empirical Growth Models. University of Oxford. Oxford: C.E.P.R. Discussion Papers.

Callejón, M., and García-Quevedo, J. (2005). "Public subsidies to business R&D: do they stimulate private expenditures?" *Environment and Planning C: Government and Policy*, **23**, pp. 279-293.

Caselli, F., and Coleman, W. (2006). "The World Technology Frontier." *American Economic Review*, **96**(3), 499-522.

Castellani, D., Montresor, S., Schubert, T., and Vezzani, A. (2017). "Multinationality, R&D and productivity: Evidence from the top R&D investors worldwide." *International Business Review*, **26**(3), 405–416.

Ciriaci, D., Grassano, N., and Vezzani, A. (2019). "Regulations and location choices of top R&D investors worldwide." *Structural Change and Economic Dynamics*, **49**, pp. 29–42.

Coad, A. (2008). "Distance to Frontier and Appropriate Business Strategy." *Papers on Economics and Evolution 2008-07*, Max Planck Institute of Economics, Evolutionary Economics Group.

Coad, A. (2011). "Appropriate business strategy for leaders and laggards." *Industrial and Corporate Change*, **20**(4), 1049-1079.

Coccia, M. (2010). "Public and private R&D investments as complementary inputs for productivity growth." *International Journal of Technology Policy and Management*, **10**(1/2), pp. 73–91.

Coccia, M. (2011). "The interaction between public and private R&D expenditure and national productivity." *Prometheus*, **29**(2), pp. 121-130.

D'Este, P., Iammarino, S., and Guy, F. (2013). "Shaping the formation ofuniversity–industry research collaborations: what type of proximity doesreally matter?" *Journal of Economic Geography*, **13**(4), pp. 537–558.

David, P., Hall, B., and Toole, A. (2000). "Is public R&D a complement or substitute for private R&D? A review of the econometric evidence." *Research Policy*, **29**(4-5), pp. 497–529.

Davidson, R., and Mackinnon, J. (2004). *Econometric Theory and Methods*. New York: Oxford University Press.

European Commission. (2016). The 2016 EU Industrial R&D Investment Scoreboard. OECD. Luxemburgo: Publications Office of the European Union. Retrieved from Publications Office of the European Union.

Goolsbee, A. (1998). "Does government R&D policy mainly benefit scientists and engineers?" *American Economic Review Papers and Proceedings*, **88**, pp. 298-302.

Görg, H., and Strobl, E. (2007). "The Effect of R&D Subsidies on Private R&D." *Economica*, **74**, pp. 215-234.

Greene, W. (2012). *Econometric Analysis* (7ª ed.). Boston, MA: Prentice Hall.

Griffith, R., Harrison, R., and Reenen, J. (2006). “How Special Is the Special Relationship? Using the Impact of U.S. R&D Spillovers on U.K. Firms as a Test of Technology Sourcing.” *American Economic Review*, **96**(5), pp. 1859-1875.

Griliches, Z. (1992). “The Search for R&D Spillovers.” *The Scandinavian Journal of Economics*, **94**, pp. S29-S47.

Grossman, G., and Helpman, E. (1994). *Innovation and Growth in the Global Economy*. Cambridge MA: The MIT Press.

Hall, B. (2000). Innovation and market value. In R. Barrell, G. Mason and M. O’mahoney (Eds.), *Productivity, Innovation and Economic Performance* (pp. 177-198). Cambridge: Cambridge University Press.

Hall, B. and Lerner, J. (2009). The Financing of R&D and Innovation. Cambridge, MA: *NBER Working Paper*, Working Paper nº 15325.

Hall, B., Mairesse, J., and Mohnen, P. (2010). Measuring the Returns to R&D. In B. Hall, & N. Rosenberg, *Handbook of the Economics of Innovation* (Vol.2, pp. 1033-1082). Amsterdan: North-Holland by Elsevier.

Hall, B., Lotti, F. and Mairesse, J. (2013). Evidence on the impact of R&D and ICT investments on innovation and productivity in Italian firms. *Economics of Innovation and New Technology*, **22**(3), 300-328.

Hamilton, L. (2013). *Statistics with Stata: Version 12* (Eighth ed.). Boston, MA: Cengage Learning.

Hayashi, F. (2000). *Econometrics*. Princeton, NJ: Princeton University Press.

Howe, J., and Mcfetridge, D. (1976). “The determinants of R&D expenditures.” *Canadian Journal of Economics*, **9**, pp. 57–71.

Hu, A. (2001). Ownership, Government R&D, Private R&D, and Productivity in Chinese Industry. *Journal of Comparative Economics*, **29**, 136–157.

Hsiao, C., and Zhang, J. (2015). “IV, GMM or likelihood approach to estimate dynamic panel models when either image or image or both are large.” *Journal of Econometrics*, **187**(1), 312-322.

Jaffe, A. (1986). “Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value.” *American Economic Review*, **76**(5), pp. 984-1001.

Kleibergen, F., and Paap, R. (2006). “Generalized Reduced Rank Tests Using the Singular Value Decomposition.” *Journal of Econometrics*, **133**(1), 97-126.

Kwon, H., and Kwon, I. (2019). “R&D Spillovers for Public R&D Productivity.” *Global Economic Review*. doi:10.1080/1226508X.2019.1638812

Lach, S. (2002). Do R&D Subsidies Stimulate or Displace Private R&D? Evidence from Israel. *Journal of Industrial Economics*, **50**(4), 369–390.

Lichtenberg, F. (1988). The private R&D investment response to federal design and technical competitions. *American Economic Review*, **78**, 550–559.

Maietta, O. (2015). “Determinants of university–firm R&D collaboration and its impact on innovation: A perspective from a low-tech industry.” *Research Policy*, **44**(7), pp. 1341–1359.

Montresor, S., and Vezzani, A. (2015). “The production function of top R&D investors: Accounting for size and sector heterogeneity with quantile estimations.” *Research Policy*, **44**(2), 381–393.

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

Park, W. (1995). “International R&D spillovers and OECD economic growth.” *Economic Inquiry*, **33**(4), pp. 571-591.

Perotti, R. (1999). Fiscal Policy in Good Times and Bad. *The Quarterly Journal of Economics*, **114**(4), 1399–1436.

Puhani, P. (2000). The Heckman Correction for Sample Selection and Its Critique. *Journal of Economic Surveys*, **14**(1), 53–68.

Rocha, L., Cardenas, L., Lopes, F., Oliveira, F., and Fernandes, K. (2018). “The Impact of R&D Investments on Performance of Firms in Different Degrees of Proximity to the Technological Frontier.” *Economics Bulletin*, **38**(2), 1156-1170.

Rocha, L., Lima, P., Khan, A., and Sousa, E. (2019). "R&D Spillovers, Innovation and Market Value: evidence of absorptive capacity in the generation of clean technologies." *Estudios de Economía Aplicada*, **37**(2), pp. 1-14.
Romer, P. (1990). "Endogenous technological change." *Journal of Political Economy*, **98**(5), S71-S102.
Segerstrom, P. (2000). "The Long-Run Growth Effects of R&D Subsidies." *Journal of Economic Growth*, **5**(3), pp. 277–305.
Shioji, E. (2001). "Public Capital and Economic Growth: A Convergence Approach." *Journal of Economic Growth*, **6**(3), pp. 205–227.
Toivanen, O. and Niininen, N. P. (1998). Investment, R&D, subsidies and credit constraints. *Working Paper*, *Department of Economics MIT and Helsinki School of Economics*.
Verardi, V., & Croux, C. (2009). "Robust regression in Stata." *The Stata Journal*, **9**(3), pp. 439–453.
Wallsten, S. (2000). The Effects of Government-Industry R&D Programs on Private R&D: The Case of the Small Business Innovation Research Program. *The RAND Journal of Economics*, **31**(1), 82-100.
White, H. (1980). "A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity." *Econometrica*, **48**, 817–838.