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Scientific output: labor or capital intensive? An analysis for selected countries

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Abstract Scientific research contributes to sustainable economic growth environments. Hence, policy-makers should understand how the different inputs—namely labor and capital—are related to a country's scientific output. This paper addresses this issue by estimating output elasticities for labor and capital using a panel of 31 countries in nine years. Due to the nature of scientific output, we also use spatial econometric models to take into account the spillover effects from knowledge produced as well as labor and capital. The results show that capital elasticity is closer to the labor elasticity. The results suggest a decreasing return to scale production of scientific output. The spatial model points to negative spillovers from capital expenditure and no spillovers from labor or the scientific output.

Keywords Scientific output · Capital · Labor · Spillover effects

JEL Classifications O32 · F01 · O15

Introduction

Research performance is a powerful indicator to assess the economic efficiency of a nation. For instance, nations with high productivity and economic output are also the leaders in patent and research output (Adams et al. 2013). Increasing scientific outcomes is necessary

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for technological changes, which may further develop the productivity and economic performance. Ultimately, it ends up increasing the national wealth and long-run sustainable economy growth.

In a globalization context, competitiveness is a common way to be an economic pioneer. Therefore, countries are striving to improve their scientific capacity (Adams et al. 2013). The authors emphasize that more than two-thirds of research published in 1973 occurred in well-established economies, whereas the trend has changed in recent years. Nowadays, only half of the journal publications have an author from G7 countries (Adams et al. 2013), indicating that developing countries are improving their scientific standing.

The aim of this study is to investigate the nature of research outcomes by answering the question of what is structure of scientific publication among nations. By answering this question, we are able to understand how countries use their available capital and labor to produce scientific outcome, and which of the inputs is more important in production. In turn, policymakers can use this information when deciding where to allocate resources; for example, investing in more education to develop researchers or investing in machinery for labs.

In general, there are two ways to increase the output of the economy: increase the volume of inputs entering the production cycle, or a more wisely alternative, increase productivity and efficiency of the production process (Rosenberg 2014). Due to scarcity of resources, nations have focused on improving productivity. Investment on research and development is an important component of long-term economic growth as it is responsible for changes in productivity.

Research and development are mostly discussed in literature in three broader areas: the effectiveness of research and development (R&D) on economic growth, how R&D influences productivity, and the relative importance of the R&D investment on research outcomes. In "Research and development (R&D) and economy growth" section we expand this discussion, concentrating on the effectiveness of research and development on research outcomes, which is the main focus of this paper.

To address the question of how nations produce their research outcome, we assume a simple production function and estimate the output elasticities for each input—labor and capital. We use a balanced panel of 31 countries from 2003 to 2011. Our results suggest that investing in researchers contributes more to the research outcomes than investing in research capital, especially because the number of researchers in higher education is the largest contributor to research outcomes. These results are not novel, but they are important because they corroborate previous studies. Also, the results help policymakers choose the appropriate pathway to enhance efficiency in resource allocation.

Our contribution to the literature is twofold. On one hand, we introduce spatial analysis to evaluate the effects of R&D inputs on scientific output in the scope of countries, which is a novel approach to the best of our knowledge. As Bonaccorsi and Daraio (2005) pointed out that physical proximity in science may be important due to complementarity between codified and tacit knowledge. On the other hand, we tackle our research question by using two different datasets: the World Bank and the OECD data, which allow us to cross validate our results.

The remainder of the paper is as follows: "Research and development (R&D) and economy growth" section discusses the R&D literature and how it is related to growth, productivity and spillovers; "Model and econometric approach" section describes our econometric approach; "Data" section presents the data used; "Results" section discusses the results; and "Discussion and implications" section concludes.

Research and development (R&D) and economy growth

Schumpeter (1942) and Solow (1957) are pioneers in the study of “innovation” and “technical changes” as engines to production and economic growth. King (2004) argues that “the ability to judge a nation’s scientific standing is vital for both governments and society”, as the result of scientific efforts may be seen in higher economic growth rates and more economic outputs. These eventually reflect the increase in social welfare.

Long-term economic growth needs a sustainable fuel, which could be provided by innovations. In long run, the ability of a nation to improve the standard of living passes through increasing the output-to-input ratio. A broad overview in productivity triggers is presented in the literature, most of them emphasizing technology and research. For instance, van Pottelsberghe de La Potterie and Guellec (2001) analyzes 16 OECD countries and finds that R&D is an important factor for productivity and economic growth. Rouvinen (2002) studies four issues in R&D and productivity. His results suggest that R&D investment influences productivity—not vice versa. Bravo-Ortega and Marin (2011) provide evidence that corroborates Rouvinen (2002)’s results.

More recently, Eid (2012), using country-level data for 17 high-income OECD countries, measures the correlation between R&D and productivity growth and finds there is a lag between them. In the tradition of the knowledge-capital model of Griliches, Doraszelski and Jaumandreu (2013) develop a model to investigate the correlation between R&D and productivity. The authors find R&D expenditure has a key role in productivity across firms.

For scientometrics, scientific publication is the engine of economic growth. Therefore, the knowledge spillover discussion becomes relatively more important. This discussion started Alfred Marshall (Carlino et al. 2001), and it still gets the attention of many economists. Some of the researches on knowledge spillovers are summarized below.

Griliches (1986) finds that after controlling for industry-specific fixed effects, the effects of research on productivity growth is cut by about fifty percent. The author explains this is because of spillovers within the industry. Jaffe (1989) and Jaffe et al. (1993) show that spillovers are industry and geographically localized. Varga (2000) applies the Griliches-Jaffe knowledge production function and expands it to a hierarchical version to test the knowledge spillovers in U.S. metropolitan areas, finding that research universities can increase the regional production. More recently, Elhorst and Zigova (2014) find no evidence of cross-fertilization effects across nearby universities, which corroborates the Bonaccorsi and Daraio’s (2005) results. However, the authors argue that collaboration has a positive effect on research productivity.

R&D and research outcomes

In an oversimplification scenario, research and development (R&D) has two major inputs and two major outputs, capital and labor for the former, and patents and publications for the latter. In this work, we focus only on the publication output. McAllister and Wagner (1981) examine the relationship between R&D expenditure and the number of papers published in a sample of 500 universities and colleges in the United States. For each of 11 fields of science that the authors consider, there is a strong positive relationship between R&D expenditure and the number of publications. Focusing only on late industrial countries, Amsden and Mourshed (1997) examine the scientific publication, patent and technological capabilities. While the authors expect a high growth rate of GDP and scientific publications to be positively correlated, they find the high correlation in countries like South Korea, China and Singapore rather than in countries such as Turkey, Argentina, Brazil, Chile and Mexico.

Shelton (2008) compares American and European publications and finds that the effectiveness of research investment is more significant than the number of scientists for scientific outcomes. Sharma and Thomas (2008) finds that the number of efficient countries in the R&D sector varies based on the assumption the authors made. Crespi and Geuna (2008) find a strongly positive long-run relationship between R&D expenditure and the number of publications with an optimum lag of 6 years. Adams et al. (2013) look at Brazil, Russia, India, China and South Korea, known together as the BRICK nations. They find Brazil stands out as different from the others. While a natural knowledge economy is a leading area in Brazil, research policy, physics, chemistry, engineering and materials are the leading areas in Russia, India, China, and South Korea.

Akhmat et al. (2014) evaluate the relationship between educational indicators and research outcomes in the top twenty countries. The results indicate that education expenditures and the number of publications have a one-to-one relationship. In a series of papers, Meo and Usmani (2014) and Meo et al. (2013a, b) found among Asian countries, Middle East, and European countries a positive correlation between spending on R&D and the number of research publications, while in all the sub-samples the results show no correlation between GDP per capita and the total number of publications. They also conclude that the research outcome depends on the ratio of R&D expenditure to the total GDP—not the absolute R&D expenditure.

Therefore, there are two mechanism into effect on R&D expenditures and research outcome. As in any type of production process, the output of research is what it is produced and published. Publishing a new scientific output is a way of transmitting knowledge in the scientific community (Mueller 2016). To produce new articles, we need researchers who will raise hypothesis and test them in different ways, and submit their papers to peer-review journal for publication. Complementary to the research, countries need to provide computers and other capital goods that allow the researcher to test his hypothesis. These two elements should be complementary. However, it is important to understand how they complement each other, as higher capital goods can increase the current researchers' productivity. This in turn, can increase the opportunity cost of investing in new researchers, as this is a long-term investment, especially if we consider their formation stage.

Model and econometric approach

Assume countries produce scientific research following a Cobb-Douglas production function in which there are two main inputs: capital and labor.

$$Y = K^{\alpha} L^{\beta} \tag{1}$$

By assuming a Cobb–Douglas, we implicitly assume that there is no heterogeneity between countries. At first this may seem unreasonable; however, given the easy access to internationally produced research through the Internet, and globalization, which allows more trade and movement between countries of both goods and people, it is possible to assume that scientific research is a homogenous produced good.

In order to estimate the model, we can transform Eq. 1 by taking the natural logarithm on both sides. After some manipulation we have

$$\ln(Y) = \alpha \ln(K) + \beta \ln(L) \quad (2)$$

We do not make any assumptions on the parameters such that, the production function can be constant, increasing, or decreasing returns to scale. Parameters α and β are the share of each input used in the production of one unit of output; hence, the bigger the parameter, the more it is used in the production. Thus, the estimated model is

$$\ln(\mathrm{SO}) = \beta_0 + \beta_1 \mathrm{CO} + \beta_2 \mathrm{Res} + \mu_{\mathrm{c}} + \delta_{\mathrm{t}} + \epsilon \quad (3)$$

where SO is the scientific output measured as the number of scientific and technical journal articles, CO is capital outlay, Res is the number of researchers in R&D, μ_{c} is the country fixed effect and δ_{t} is year fixed effect. Notice that introducing country fixed effect we are able to control for institutional differences among countries.

One important feature of the labor input, which is even more important in the case of scientific output, is the knowledge from the worker. As argued by Griliches (1986), knowledge spillovers are expected to exist. Therefore, we incorporate this feature into our model by using a spatial model that follows the general formulation:

$$Y = \rho W_1 Y + X\beta + W_1 X\tau + \xi \quad (4)$$

$$\xi = \lambda W_2 \xi + \varepsilon \quad (5)$$

such that $\varepsilon \sim (0, \sigma^2 I)$.

According to the LeSage and Pace (2009) and Elhorst (2014), under non-spatial econometric estimation, observations do not depend on location. They are independent points and therefore there is no correlation between them and their neighbors. However, LeSage and Pace (2009) explains: “In contrast to point observations, for a region we rely on the coordinates of an interior point representing the center (the centroid). An important point is that in spatial regression models each observation corresponds to a location or region” (LeSage and Pace 2009, p. 1). In non-spatial models, each observation has a mean of $x_i\beta$ and a random component ε_i where the observation i represents a region or point in space at one location. Plus, it is considered independent of observations in other locations. In other words, independent or statistically independent observations imply that $E(\varepsilon_i\varepsilon_j) = E(\varepsilon_i)E(\varepsilon_j) = 0$. This assumption of independence greatly simplifies models.

In most cases this assumption is not applicable. Observations in different points or regions are dependent of each other (LeSage and Pace 2009). Suppose we have two neighboring regions i and j. If these two regions are spatially correlated and normality for error terms is assumed then:

$$y_i \leftrightarrow y_j$$

where the dependent variable (y) in region j influences the dependent variable in its neighbor region i, and vice versa.

There are five different types of spatial models. In order to capture the knowledge spillover, we will focus on four models: the Spatial Durbin model (SDM) in which we include W_1Y and W_1X on the right-hand side; the Spatial Durbin error model (SDEM) that expands the SDM model by introducing $\lambda W_2\xi$ in the right-hand side; the Spatial Autoregressive Lag model (SAR) in which we include only W_1Y; and, the Spatial Lag of X model (SLX) in which we include only W_1X. The best model will be the one that deals with the spatial dependence and has the better adjustment measured by the Schwartz (BIC) and Akaike (AIC) statistics.

As one can notice, all spatial models have a weight matrix (*W*), which quantifies the connections between regions. Elhorst (2014) defines the weight matrix as a tool to describe the spatial arrangement of the geographical units in the sample. There are variety of units of measurement for spatial dependency such as neighbors, distance, and links (Getis 2007). In this study, we applied the *k*-nearest neighbor weight matrix. For more details on the difference between the spatial weight matrices, please refer to Elhorst (2014) and Getis (2007)

Collaboration and communication in modern science between scientists in not a new topic in research literature. With an increase in the number of scientists in one region, there may exist more interactions between researchers from neighboring regions, which in turn can influence the production of scientific output (scientific publication) in these neighboring regions as well. On the other hand, if capital is being invested in one particular region, one may expect that there will be less capital available to invest in other regions, particularly in neighboring regions. Therefore, we expect that, if there are some spillover effects they will be positive for the scientific output and researchers, but negative for capital investment.

Data

Data for constructing the model come from two different sources: The World Bank (WB) dataset[1] and the Organization for Economic Cooperation and Development (OECD) dataset.[2] The list of countries in each set of analysis is provided in “Appendix 1”. Because the number of countries in each dataset differs, we estimate two different sets of models, one for each source.

The World Bank provides the number of scientific and technical journal articles[3] for all the countries around the world. The dependent variable for all the specifications is based on the World Bank. Explanatory variables for scientific inputs in the World Bank model includes the number of researchers in R&D and R&D expenditures. The latter is calculated by multiplying the percent of R&D expenditures obtained from the World Bank website, such as in Mueller (2016), by the GDP in 2003 dollars. This dataset includes 31 countries in a panel of nine years from 2003 to 2011.

The OECD explanatory variables include the full-time equivalent researchers in total, and we further break it down to business enterprise, government, and higher education sectors. The total labor cost and the total capital expenditure in research are the capital related input in OECD countries analysis This dataset contains 22 countries from 2003 to 2011.

The scientific output information is available for 46 countries from 1996 to 2011 in an unbalanced set up. Because we believe the use of spatial econometrics techniques are very important in this study, we created a balanced panel of countries that maximized the number of observations. Therefore, we attempt to deal with these possible concerns, but to have a balanced panel, we have to drop 9 other countries that were in the World Bank sample. Moreover, we chose to use of both World Bank and OECD datasets because by doing so we can cross-validate our results using two different dataset that are commonly used in the literature. Table 1 provides the summary statistics for the data.

One possible concern with the dependent variable (the number of articles published in Scientific Journals for each country) is how this allocation is done. According to World

[1] Available at: http://data.worldbank.org/indicator.

[2] Available at: http://stats.oecd.org/.

[3] http://databank.worldbank.org/data/reports.aspx?source=2&type=metadata&series=IP.JRN.ARTC.SC.

Table 1 Descriptive statistics

Variable	Source	N	Mean	SD	Min	Max
World bank sample						
# of articles	World Bank	279	20,521.3	37,990.1	354.6	212,883.0
Total # of researchers WB	World Bank	279	3126.4	1812.8	301.5	8003.5
Real R&D expenditure	World Bank	279	1.687	0.947	0.368	4.039
OECD sample						
# of articles	World Bank	198	12,465.8	16,306.8	874.9	89,894.4
Total # of researchers OECD	OECD	198	152,079.0	283,872.4	3775.0	1592,420.0
Researchers in business enterprises	OECD	198	89,770.3	186,084.8	1516.0	1092,213.0
Researchers in government	OECD	198	24,570.3	52,255.5	1044.0	250,250.0
Researchers in higher education	OECD	198	36,604.6	53,214.3	1178.0	261,237.0
Labor cost on R&D	OECD	198	8915.4	14,101.0	190.5	64,252.0
Capital expenditure on R&D ($MM)	OECD	198	2632.6	5979.1	44.6	34,867.9

Bank[4] articles with authors from different countries are allocated proportionately to each country. Also, articles are limited to the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences. Although this database cover the core set of scientific journals, it may exclude local and national journals and other fields too. As for the explanatory variables, one may be concerned about the collinearity between R&D expenditures and number of researchers as the former may include the latter (payroll expenditures). This is less of a concern in the OECD sample, but nevertheless we performed variance inflation factor (VIF) tests and the results did not show signs of multicollinearity.

Results

The results are divided into two parts.[5] First, we present the results without any spatial spillovers and then we introduce such results.[6] As explained in the previous sections, we believe that the spatial spillovers are important both theoretically and empirically. Tables 2, 3, 4 and 5 present the results with no spatial dependence. The analysis will focus

[4] http://data.worldbank.org/indicator/IP.JRN.ARTC.SC.

[5] One important discussion in the literature as described in Mueller (2016) is the lagged (delayed) effect of R&D investment on research outcome. In the “Appendix 2”, we present results using one year lagged on the explanatory variables.

[6] All the results presented in this paper uses linear models. However, Gantman (2012) points that one should consider count-data models when there is the possibility of skewed data, i.e., standard deviations larger than the means. We compared the negative binomial models with the linear models, and used the Akaike Information Criteria to determine that the linear models outperform the count data regression. These results are available upon request.

Table 2 World Bank sample results

	Dependent variable: articles			
	OLS	Fixed effect		
	(1)	(2)	(3)	(4)
Real R&D expenditure	0.768***	0.368***	0.769***	0.354***
	(0.013)	(0.031)	(0.013)	(0.041)
Total # of researchers WB	−0.269***	0.085	−0.265***	0.061
	(0.029)	(0.053)	(0.030)	(0.056)
Constant	2.603***			
	(−0.219)			
Year FE			X	X
Country FE		X		X
Observations	279	279	279	279
R^2	0.934	0.997	0.935	0.997
Adjusted R^2	0.934	0.996	0.933	0.996

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the fixed effects model we used the package "lfe" in *R*

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

on model (4), our preferred specification. Because we are not able to make any causal inference we do not discuss the magnitude of our elasticities in depth and only compare them against each other for the models we tested.

Table 2 presents the results using the number of researchers provided by the World Bank (WB) and the gross capital formation, also provided by the World Bank. The results show no influence of capital on the scientific output, while the elasticity of labor is positive and statistically significant. To further investigate[7] this relationship, we look at another data source. Table 3 presents results using labor cost as a proxy for the number of researchers in R&D and capital cost, Table 4 uses the total number of researchers, and Table 5 disaggregates the researchers into three categories: business enterprise, government and higher education. The dependent variable remains the number of articles produced reported by the World Bank.

The results for the preferred model (4) from Tables 3, 4 and 5 show a positive and statistically significant result for both capital and labor. According to the elasticity values, there is decreasing returns to scale relation, as the sum of both elasticities are less than one in every case. It is interesting to note when using the number of researchers instead of the labor cost (Tables 4, 5) the results suggest the capital and labor elasticities have similar magnitude.

[7] Another robustness check performed was the analysis for unbalanced panels in all scenarios discussed. The results remain similar in terms of sign and significance of the estimated coefficients. These results are available upon request.

Table 3 OECD sample results

	Dependent variable: articles			
	OLS	Fixed effect		
	(1)	(2)	(3)	(4)
Capital expenditure on R&D	0.305***	0.224***	0.307***	0.129***
	(0.031)	(0.032)	(0.031)	(0.034)
Labor cost on R&D	0.475***	0.102***	0.477***	0.047*
	(0.032)	(0.027)	(0.033)	(0.027)
Constant	2.918***			
	(0.122)			
Year FE			X	X
Country FE		X		X
Observations	198	198	198	198
R^2	0.936	0.992	0.938	0.993
Adjusted R^2	0.936	0.990	0.934	0.992

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the fixed effects model we used the package "lfe" in *R*

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 4 OECD sample results, researchers

	Dependent variable: articles			
	OLS	Fixed effect		
	(1)	(2)	(3)	(4)
Capital expenditure on R&D	0.439***	0.161***	0.444***	0.124***
	(0.040)	(0.032)	(0.041)	(0.034)
Total # of researchers OECD	0.348***	0.351***	0.345***	0.178**
	(0.045)	(0.055)	(0.046)	(0.069)
Constant	2.100***			
	(0.284)			
Year FE			X	X
Country FE		X		X
Observations	198	198	198	198
R^2	0.896	0.993	0.897	0.994
Adjusted R^2	0.895	0.992	0.891	0.992

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the fixed effects model we used the package "lfe" in *R*

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 5 OECD sample results, disaggregated researchers

	Dependent variable: articles			
	OLS	Fixed effect		
	(1)	(2)	(3)	(4)
Capital expenditure on R&D	0.311***	0.143***	0.314***	0.114***
	(0.045)	(0.031)	(0.046)	(0.033)
Researchers in business enterprises	0.201***	−0.034	0.200***	−0.061
	(0.039)	(0.038)	(0.040)	(0.038)
Researchers in government	−0.083**	0.148***	−0.087**	0.116**
	(0.037)	(0.054)	(0.038)	(0.054)
Researchers in higher education	0.393***	0.371***	0.398***	0.281***
	(0.060)	(0.054)	(0.062)	(0.062)
Constant	1.609***			
	(0.286)			
Year FE			X	X
Country FE		X		X
Observations	198	198	198	198
R^2	0.910	0.994	0.911	0.994
Adjusted R^2	0.908	0.993	0.905	0.993

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the fixed effects model we used the package "lfe" in *R*

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Spatial models

As discussed in the previous sections, it is important to consider the spillover effects of knowledge both theoretically and empirically. Therefore, we present in Tables 6, 7, 8 and 9 the spatial results for the regressions presented in Tables 2, 3, 4 and 5. We present four spatial models: SAR, SDM, SDEM and SLX; however, we will focus the analysis on the SDM model as we believe it is the best model because it considers spillovers from the dependent variables (articles) and the explanatory variables (inputs). In terms of the weight matrix, we used the k-nearest neighbors weight matrix with k equals to 1. This was the weight matrix that captured the most spatial dependence.

For the World Bank sample (Table 6) we observe that the results remain similar to those of Table 2, but there is an extra weight on the labor elasticity. Also, there is no evidence of articles or input spillover, which suggests countries have access to the same information regardless if they are neighbors. As for the OECD sample (Tables 7, 8, 9), there is statistically significant negative spillover of capital expenditure on R&D. This suggests that investing in R&D has a negative effect on knowledge output in close-by countries. There is no spillover of labor inputs nor of scientific outputs. Also, the countries own labor and capital inputs have positive and statistically significant results.

One possible concern is the use of the geographical matrix to do the spatial analysis. We would argue that this matrix is good for several reasons. Firstly, we need the weight matrix to be exogenous to our estimation, and the geographic matrix fits this requirement.

Table 6 World Bank sample spatial results

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Real R&D expenditure	0.350***	0.347***	0.341***	0.350***
	(0.038)	(0.038)	(0.036)	(0.041)
Total # of researchers WB	0.064	0.064	0.086*	0.060
	(0.051)	(0.051)	(0.050)	(0.055)
$W \times$ articles	0.039	0.042		
	(0.045)	(0.045)		
$W \times$ real R&D expenditure		−0.005	−0.005	−0.004
		(0.003)	(0.003)	(0.004)
$W \times$ total # of researchers WB		0.007	0.005	0.007
		(0.007)	(0.007)	(0.008)
$W \times$ error term			0.109*	
			(0.048)	
Country FE	X	X	X	X
Year FE	X	X	X	X
R^2				0.996
Number of observations	279	279	279	279

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the spatial models SAR, SDM and SDEM we used the package “splm” in *R*, and for the SLX the package “lfe”

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Secondly, it is well established in the literature that distance has an inverse relation to economic outcomes. Lastly, several authors (Jaffe 1989; Jaffe et al. 1993; Varga 2000) show that geographical proximity is important for spillovers.

Discussion and implications

The objective of this paper is to understand the production of scientific output for several countries. More specifically, we wanted to investigate the relation of capital and labor employed in research to its output. We used a balanced panel of 31 countries and 9 years to estimate the capital and labor elasticities and then employed spatial models in order to capture possible spillovers. The main results can be divided into two: firstly, capital and labor seems to have similar importance in terms of producing scientific output as their magnitudes are similar; and when disaggregated, researchers in the business enterprise have zero output elasticity. Secondly, in terms of spillovers, there seems to be a negative spillover in R&D capital expenditure. Also, there is no spillovers of scientific output (articles) in all spatial specifications.

One important discussion is to compare our results to the existing literature. Most papers when looking at scientific output, focus on patents (“Research and development (R&D) and economy growth” section) which is not the case of this paper, and we believe

Table 7 OECD sample spatial results

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Capital expenditure on R&D	0.129***	0.139***	0.138***	0.140***
	(0.031)	(0.030)	(0.031)	(0.033)
Labor cost on R&D	0.048*	0.051**	0. 051**	0.051*
	(0.024)	(0.024)	(0.024)	(0.026)
$W \times$ articles	−0.023	−0.023		
	(0.059)	(0.059)		
$W \times$ capital expenditure on R&D		−0.109***	−0.110***	−0.109***
		(0.034)	(0.033)	(0.037)
$W \times$ labor cost on R&D		0.011	0.001	0.011
		(0.019)	(0.019)	(0.021)
$W \times$ error term			−0.030	
			(0.063)	
Country FE	X	X	X	X
Year FE	X	X	X	X
R^2				0.993
Number of observations	198	198	198	198

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor For the spatial models SAR, SDM and SDEM we used the package "splm" in *R*, and for the SLX the package "lfe"

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

has different incentives and mechanisms into place. Therefore, we focus on those papers discussing scientific output in general. Our results suggest that both capital and researchers are important in the production of articles which is similar to the findings of Mueller (2016), who finds R&D expenditure to be more important than researchers. However, for our results, the WB sample suggests capital to be more important while the OECD sample suggests that the number of researchers, are the most important.

Koljatic and Silva (2001) find that communication of results is important for scientific progress. Our results don't show evidence of spillovers from the published articles, which may imply that the access to published articles are homogeneous between countries, especially because we focus on a post-internet period. Sarwar and Hassan (2015) shows that having a similar culture seems to matter in terms of collaboration, while Vinluan (2011) looks at the relationship between the Association of Southeast Asian Nations and Phillipines and conclude the latter are less collaborative than other members. We did not test the cultural hypothesis specifically or which countries do collaborate more. However, because our weight matrix captures the nearest country we can assume, they should share many similarities and should have more collaboration, i.e., spillovers. Unfortunately, the results show not statistical significance.

In terms of policy implication, the results suggest similar importance of both capital and labor in the production of scientific outputs. Moreover, the results imply that research in government agencies and workers in higher education produce more scientific output. This is important, especially in developing countries, as government offers better careers in

Table 8 OECD sample spatial results, researchers

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Capital expenditure on R&D	0.120***	0.130***	0.131***	0.133***
	(0.031)	(0.030)	(0.030)	(0.033)
Total # of researchers OECD	0.189***	0.206***	0.209***	0.201***
	(0.062)	(0.064)	(0.063)	(0.070)
$W \times$ articles	−0.055	−0.044		
	(0.059)	(0.058)		
$W \times$ capital expenditure on R&D		−0.077***	−0.114***	−0.111
		(0.075)	(0.032)	(0.033)
$W \times$ total # of researchers OECD		0.064	0.079	0.080
		(0.076)	(0.076)	(0.084)
$W \times$ error term			−0.059	
			(0.063)	
Country FE	X	X	X	X
Year FE	X	X	X	X
R^2				0.993
Number of observations	198	198	198	198

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the spatial models SAR, SDM and SDEM we used the package "splm" in *R*, and for the SLX the package "lfe"

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

terms of stability and income even though it offers little incentive in the production of new scientific output. However, because we cannot claim a causal effect, we cannot affirm that the magnitude of the estimated coefficients are the true effect of additional units of labor and capital on research outcomes.

Future research should focus on improving the current limitations of this paper. For instance, one could work on the data availability to incorporate different countries in the analysis, and address an external validity concern. Also, one important improvement would be to use some identification strategy that allows causal inference, hence providing not only more accurate estimations of the true impact, but also better policy recommendation as the "true effect" would be known. Other possible extensions are: the estimation of the elasticities assuming heterogeneous production functions for each country and the use of "economic" weight matrix, which would capture the closest economic relations between the countries. As discussed previously, the challenge in this last part is to guarantee the weight matrix is exogenous to the estimations. Although the paper has some limitations, the results are still interesting and contribute to the discussion in the literature of the impact of labor and capital in research outcomes.

Table 9 OECD sample spatial results, disaggregated researchers

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Capital expenditure on R&D	0.111***	0.107***	0.107***	0.112***
	(0.030)	(0.029)	(0.030)	(0.033)
Researchers in business enterprises	−0.056	0.001	0.003	−0.006
	(0.034)	(0.039)	(0.040)	(0.044)
Researchers in government	0.118**	0.115**	0.111**	0.111**
	(0.049)	(0.047)	(0.048)	(0.053)
Researchers in higher education	0.282***	0.212***	0.205***	0.217***
	(0.056)	(0.059)	(0.060)	(0.066)
$W \times$ articles	−0.036	−0.063		
	(0.056)	(0.055)		
$W \times$ capital expenditure on R&D		−0.069**	−0.075**	−0.070*
		(0.034)	(0.034)	(0.038)
$W \times$ researchers in business enterprises		0.053	0.062*	0.057
		(0.036)	(0.037)	(0.040)
$W \times$ researchers in government		−0.025	−0.020	−0.020
		(0.054)	(0.054)	(0.060)
$W \times$ researchers in higher education		−0.120	−0.120	−0.098
		(0.075)	(0.075)	(0.083)
$W \times$ error term			−0.069	
			(0.063)	
Country FE	X	X	X	X
Year FE	X	X	X	X
R^2				0.994
Number of observations	198	198	198	198

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the spatial models SAR, SDM and SDEM we used the package "splm" in *R*, and for the SLX the package "lfe"

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

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Appendix 1

See Table 10.

Table 10 Counties in World Bank and OECD samples

Countries	World Bank	OECD
Argentina	X	X
Belgium	X	X
Canada	X	
China	X	X
Czech Republic	X	X
Denmark	X	X
Estonia	X	
Finland	X	X
France	X	X
Germany	X	
Hungary	X	X
Ireland	X	
Italy	X	X
Japan	X	X
Korea	X	X
Mexico	X	
Netherland	X	X
Norway	X	X
Poland	X	X
Portugal	X	X
Romania	X	X
Russia	X	X
Singapore	X	X
Slovak Republic	X	X
Slovenia	X	X
South Africa	X	X
Spain	X	
Sweden	X	
Turkey	X	X
United Kingdom	X	
United States	X	

Appendix 2: Results using lag variables

In this appendix, we address an important discussion in the production of scientific outcome, namely the delayed effect of investment in capital and labor on scientific output. As part of the production of scientific output, we know that to produce and publish articles time is important, as it can take several months, or years, to run an experiment, write the report and have it published. Therefore, we can expect a lag effect of capital and research investment on the output of scientific production.

Below we reproduce Tables 2, 3, 4, 5, 6, 7, 8 and 9 using a one year lag in our explanatory variables. Again, we will focus the analysis in model (4) with country and year fixed effects and the Spatial Durbin Model, both of which are our preferred models. Tables 11, 12, 13 and 14 present the non-spatial models and Tables 15, 16, 17 and 18

Table 11 World Bank sample results—lagged

	Dependent variable: articles			
	OLS	Fixed effect		
	(1)	(2)	(3)	(4)
Lagged real R&D expenditure	0.762***	0.313***	0.765***	0.337***
	(0.013)	(0.032)	(0.013)	(0.042)
Lagged total # of researchers WB	−0.273***	0.085	−0.268***	0.065
	(0.031)	(0.054)	(0.032)	(0.056)
Constant	2.730***			
	(−0.233)			
Year FE			X	X
Country FE		X		X
Observations	248	248	248	248
R^2	0.933	0.997	0.935	0.998
Adjusted R^2	0.933	0.997	0.932	0.997

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the fixed effects model we used the package "lfe" in *R*

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 12 OECD sample results—lagged

	Dependent variable: articles			
	OLS	Fixed effect		
	(1)	(2)	(3)	(4)
Lagged capital expenditure on R&D	0.345***	0.229***	0.346***	0.145***
	(0.032)	(0.031)	(0.032)	(0.034)
Lagged labor cost on R&D	0.430***	0.069***	0.433***	0.037
	(0.033)	(0.024)	(0.034)	(0.024)
Constant	3.068***			
	(0.127)			
Year FE			X	X
Country FE		X		X
Observations	176	176	176	176
R^2	0.937	0.994	0.939	0.995
Adjusted R^2	0.936	0.993	0.936	0.994

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the fixed effects model we used the package "lfe" in *R*

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 13 OECD sample results, researchers—lagged

	Dependent variable: articles			
	OLS	Fixed effect		
	(1)	(2)	(3)	(4)
Lagged capital expenditure on R&D	0.461***	0.167***	0.466***	0.136***
	(0.040)	(0.032)	(0.040)	(0.034)
Lagged total # of researchers OECD	0.321***	0.284***	0.319***	0.147
	(0.045)	(0.054)	(0.046)	(0.068)
Constant	2.283***			
	(–0.284)			
Year FE			X	X
Country FE		X		X
Observations	176	176	176	176
R^2	0.905	0.995	0.906	0.996
Adjusted R^2	0.904	0.994	0.901	0.994

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the fixed effects model we used the package "lfe" in *R*

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 14 OECD Sample results, disaggregated researchers—lagged

	Dependent variable: articles			
	OLS	Fixed effect		
	(1)	(2)	(3)	(4)
Lagged capital expenditure on R&D	0.351***	0.161***	0.354***	0.133***
	(0.046)	(0.031)	(0.047)	(0.033)
Lagged researchers in business enterprises	0.164***	−0.059	0.163***	−0.083**
	(0.041)	(0.038)	(0.042)	(0.039)
Lagged researchers in government	−0.066*	0.107**	−0.070*	0.081
	(0.039)	(0.050)	(0.040)	(0.050)
Lagged researchers in higher education	0.371***	0.332***	0.376***	0.265***
	(0.062)	(0.052)	(0.063)	(0.059)
Constant	1.820***			
	(−0.29)			
Year FE			X	X
Country FE		X		X
Observations	176	176	176	176
R^2	0.916	0.995	0.918	0.996
Adjusted R^2	0.914	0.995	0.912	0.995

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the fixed effects model we used the package "lfe" in *R*

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 15 World Bank sample spatial results, lagged

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Lagged real R&D expenditure	0.334***	0.322***	0.320***	0.324***
	(0.038)	(0.038)	(0.037)	(0.042)
Lagged total # of researchers WB	0.059	0.081	0.090*	0.079
	(0.050)	(0.051)	(0.050)	(0.056)
$W \times$ lagged articles	0.044	0.032		
	(0.047)	(0.047)		
$W \times$ lagged real R&D expenditure		−0.009*	−0.008*	−0.009*
		(0.003)	(0.003)	(0.004)
$W \times$ lagged total # of researchers WB		0.014**	0.013*	0.014*
		(0.006)	(0.006)	(0.007)
$W \times$ error term			0.091*	
			(0.052)	
Country FE	X	X	X	X
Year FE	X	X	X	X
R^2				0.997
Number of observations	279	279	279	279

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the spatial models SAR, SDM and SDEM we used the package “splm” in *R*, and for the SLX the package “lfe”

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 16 OECD sample spatial results, lagged

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Lagged capital expenditure on R&D	0.128***	0.128***	0.129***	0.143***
	(0.031)	(0.030)	(0.030)	(0.034)
Lagged labor cost on R&D	0.047*	0.040*	0. 041*	0.035
	(0.024)	(0.023)	(0.023)	(0.023)
$W \times$ lagged articles	−0.023	−0.024		
	(0.059)	(0.058)		
$W \times$ lagged capital expenditure on R&D		0.042**	0.042**	−0.009
		(0.012)	(0.012)	(0.013)
$W \times$ lagged labor cost on R&D		−0.042**	−0.042**	0.006
		(0.014)	(0.014)	(0.015)
$W \times$ error term			−0.024	
			(0.063)	

Table 16 continued

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Country FE	X	X	X	X
Year FE	X	X	X	X
R^2				0.992
Number of observations	198	198	198	198

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the spatial models SAR, SDM and SDEM we used the package "splm" in *R*, and for the SLX the package "lfe"

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 17 OECD sample spatial results, researchers, lagged

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Lagged capital expenditure on R&D	0.120***	0.117***	0.120***	0.135***
	(0.031)	(0.031)	(0.031)	(0.034)
Lagged total # of researchers OECD	0.189**	0.191**	0.183**	0.149*
	(0.062)	(0.062)	(0.062)	(0.068)
$W \times$ lagged articles	−0.055	−0.044		
	(0.059)	(0.058)		
$W \times$ lagged capital expenditure on R&D		0.013	0.013	−0.006
		(0.013)	(0.013)	(0.012)
$W \times$ lagged total # of researchers OECD		−0.004	−0.004	−0.002
		(0.014)	(0.014)	(0.014)
$W \times$ error term			−0.045	
			(0.062)	
Country FE	X	X	X	X
Year FE	X	X	X	X
R^2				0.992
Number of observations	198	198	198	198

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the spatial models SAR, SDM and SDEM we used the package "splm" in *R*, and for the SLX the package "lfe"

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

present the spatial models. Different then the results in the main text, now capital investment is positive across all models specifications but labor is not statistically significant, and when it is, it can be negative (Table 14—BE researchers). This is not a totally unexpected result, but in our opinion tells only part of the story as current researchers should be important in explaining current scientific productions.

Table 18 OECD sample spatial results, disaggregated researchers, lagged

	Dependent variable: articles			
	SAR	SDM	SDEM	SLX
Lagged capital expenditure on R&D	0.111***	0.115***	0.117***	0.125***
	(0.030)	(0.031)	(0.031)	(0.033)
Lagged researchers in business enterprises	−0.056	−0.056	−0.062*	−0.086*
	(0.034)	(0.034)	(0.034)	(0.039)
Lagged researchers in government	0.118*	0.126*	0.123*	0.077
	(0.049)	(0.050)	(0.050)	(0.051)
Lagged researchers in higher education	0.282***	0.288***	0.288***	0.284***
	(0.056)	(0.057)	(0.057)	(0.059)
$W \times$ lagged articles	−0.036	−0.048		
	(0.056)	(0.055)		
$W \times$ lagged capital expenditure on R&D		0.001	0.0008	−0.012
		(0.016)	(0.016)	(0.015)
$W \times$ lagged researchers in business enterprises		0.010	0.011	0.012
		(0.013)	(0.013)	(0.014)
$W \times$ lagged researchers in government		−0.015	−0.013	−0.008
		(0.012)	(0.012)	(0.011)
$W \times$ lagged researchers in higher education		0.006	0.004	−0.005
		(0.019)	(0.019)	(0.017)
$W \times$ error term			−0.015	
			(0.063)	
Country FE	X	X	X	X
Year FE	X	X	X	X
R^2				0.992
Number of observations	198	198	198	198

In parenthesis, we present the standard-error. The variables in the regression are in log form, so the coefficients can be interpreted as the output elasticities of capital and labor. For the spatial models SAR, SDM and SDEM we used the package “splm” in *R*, and for the SLX the package “lfe”

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Therefore, combining both results should provide a better overall picture. In term of spatial spillovers we have mixed evidences: (1) for WB Sample positive spillover of researcher and negative spillover of capital; (2) OECD Sample: positive spillover of capital and negative spillover of labor cost but no statistical significance for either capital or labor when we use the number of researcher measures. Therefore, we cannot conclude if lagged researchers and capital influenced in neighboring countries. Nevertheless, the results seems consistent with the ones presented in the main text and help to tell a better story.

References

Adams, J., Pendlebury, D., & Stembridge, B. (2013). *Building bricks: Exploring the global research and innovation impact of Brazil, Russia, India, China and South Korea*. New York: Thomson Reuters.

Akhmat, G., Zaman, K., Shukui, T., Javed, Y., & Kahn, M. M. (2014). Relationship between educational indicators and research outcomes in a panel of top twenty nations: Windows of opportunity. *Journal of Informetrics, 8*(2), 349–361.

Amsden, A. H., & Mourshed, M. (1997). Scientific publications, patents and technological capabilities in late-industrializing countries. *Technology Analysis and Strategic Management, 9*(3), 343–360.

Bonaccorsi, A., & Daraio, C. (2005). Exploring size and agglomeration effects on public research productivity. *Scientometrics, 63*(1), 87–120.

Bravo-Ortega, C., & Marín, A. G. (2011). R&D and productivity: A two way avenue? *World Development, 39*(7), 1090–1107.

Carlino, G., Chatterjee, S., & Hunt, R. (2001). Knowledge spillovers and the new economy of cities, Working Paper No 01–14, Federal Reserve Bank of Philadelphia.

Crespi, G. A., & Geuna, A. (2008). An empirical study of scientific production: A cross country analysis, 1981–2002. *Research Policy, 37*(4), 565–579.

Doraszelski, U., & Jaumandreu, J. (2013). R&D and productivity: Estimating endogenous productivity. *The Review of Economic Studies, 80*(4), 1338–1383.

Eid, A. (2012). Higher education R&D and productivity growth: an empirical study on high-income OECD countries. *Education Economics, 20*(1), 53–68.

Elhorst, J. P. (2014). *Spatial econometrics: From cross-sectional data to spatial panels* (pp. 20–25). New York: Springer.

Elhorst, J. P., & Zigova, K. (2014). Competition in research activity among economic departments: Evidence by negative spatial autocorrelation. *Geographical Analysis, 46*(2), 104–125.

Gantman, E. R. (2012). Economic, linguistic, and political factors in the scientific productivity of countries. *Scientometrics, 93*(3), 967–985.

Getis, A. (2007). Reflections on spatial autocorrelation. *Regional Science and Urban Economics, 37*(4), 491–496.

Griliches, Z. (1986). Productivity, R&D, and basic research at the firm level in the 1970s. *American Economic Review, 76*(1), 141–154.

Jaffe, A. B. (1989). Real effects of academic research. *American Economic Review, 79*(5), 957–970.

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.

King, D. A. (2004). The scientific impact of nations. *Nature, 430*(7), 311–316.

Koljatic, M., & Silva, M. (2001). The international publication productivity of Latin American countries in the economics and business administration fields. *Scientometrics, 51*(2), 381–394.

LeSage, J., & Pace, K. (2009). *Introduction to spatial econometrics*. Boca Raton: Taylor & Francis Group LLC.

McAllister, P. R., & Wagner, D. (1981). Relationship between R&D expenditures and publication output for US colleges and universities. *Research in Higher Education, 15*(1), 3–30.

Meo, S. A., Al Masri, A. A., Usmani, A. M., Memon, A. N., & Zaidi, S. Z. (2013a). Impact of GDP, spending on R&D, number of universities and scientific journals on research publications among Asian countries. *PLoS ONE, 8*(6), 1–8.

Meo, S. A., & Usmani, A. M. (2014). Impact of R&D expenditures on research publications, patents and high-tech exports among European countries. *European Review for Medical and Pharmacological Sciences, 18*(2014), 1–9.

Meo, S. A., Usmani, A. M., Vohra, M. S., & Bukhari, I. A. (2013b). Impact of GDP, spending on R&D, number of universities and scientific journals on research publications in pharmacological sciences in Middle East. *European Review for Medical and Pharmacological Sciences, 17*(20), 2697–2705.

Mueller, C. E. (2016). Accurate forecast of countries' research output by macro-level indicators. *Scientometrics, 109*(2), 1307–1328.

Rosenberg, N. (2014). Innovation and economic growth. OECD, Paris. Available at <https://www.oecd.org/cfe/tourism/34267902.pdf>

Rouvinen, P. (2002). R&D-productivity dynamics: Causality, lags, and 'dry holes'. *Journal of Applied Economics, 5*(1), 123–156.

Sarwar, R., & Hassan, S. U. (2015). A bibliometric assessment of scientific productivity and international collaboration of the Islamic World in science and technology (S&T) areas. *Scientometrics, 105*(2), 1059–1077.

Schumpeter, J. A. (1942). *Capitalism, socialism and democracy*. London: Unwin Paperbacks.

Sharma, S., & Thomas, V. (2008). Inter-country R&D efficiency analysis: An application of data envelopment analysis. *Scientometrics, 76*(3), 483–501.
Shelton, R. D. (2008). Relations between national research investment and publication output: Application to an American paradox. *Scientometrics, 74*(2), 191–205.
Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics, 39*(3), 312–320.
van Pottelsberghe de La Potterie, B., & Guellec, D. (2001). *R&D and productivity growth: A panel data analysis of 16 OECD countries*. ULB—Universite Libre de Bruxelles.
Varga, Atilla. (2000). Local academic knowledge spillovers and the concentration of economic activity. *Journal of Regional Science, 40*(2), 289–309.
Vinluan, L. R. (2011). Research productivity in education and psychology in the Philippines and comparison with ASEAN countries. *Scientometrics, 91*(1), 277–294.