Scientometrics (2012) 93:967–985
DOI 10.1007/s11192-012-0736-3

Economic, linguistic, and political factors in the scientific productivity of countries

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Received: 10 December 2011 / Published online: 13 April 2012

Abstract This paper examines the influence of economic, linguistic, and political factors in the scientific productivity of countries across selected scientific disciplines. Using a negative binomial regression model, I show that the effect of these determinants is contingent upon the scientific field under analysis. The only variable that exerts a positive and significant effect across all disciplines is the size of the economy. The linguistic variable only has a positive influence in the social sciences as well as in medicine and agricultural sciences. In addition, it is also demonstrated that the degree of political authoritarianism has a negative and statistically significant effect in some of the selected fields.

Keywords Scientific productivity · Economic development · Authoritarianism · Count models

Mathematics Subject Classification 62H15 · 62J99

JEL Classification O10 · O30

Introduction

During the twentieth century, science increasingly became a paramount institution in contemporary society, representing the epitome of modern rationality. With an aura of highly reliable source of authoritative knowledge, science constructs orderly accounts of the social and natural reality that serve to legitimate public policies; and it appears to be associated with the diffusion of values that conform a sort of universal ethos, which goes

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beyond the promotion of material aspects like economic growth to emphasize the importance of human rights and respect for the environment (Drori et al. 2003). Many less developed countries make strong efforts to foster scientific activities, despite their lack of economic resources to maintain an appropriate infrastructure to this end. This interest is based on the belief that the development of these activities contributes to economic growth or, in more general terms, to maximize the population's well-being, improving its cultural, environmental, and sanitary living conditions. However, and regardless of the widespread rhetoric about the importance of science in the so-called knowledge society, the relationship between scientific production and wealth creation has not received much empirical support (Schofer et al. 2000). It has even been affirmed that there is an inverse relation between short-term economic growth and scientific production for the less developed countries (Shenhav and Kamens 1991). Therefore, the interest of these countries in promoting scientific production appears guided more by reasons of increasing their prestige in the international community (Drori 1993) than by rational expectations.

With few exceptions (e.g., Cole and Phelan 1999; Schofer 2004), the study of the participation of countries in the international arena of scientific production has been mostly focused in understanding its consequences rather than its determinants. However, it is widely acknowledged that the creation of scientific knowledge is influenced by a multiplicity of factors, through mechanisms whose effects may operate on both the individuals that generate this knowledge and the organizations in which they carry out their activities. Diverse cultural, political, and economic aspects shape the ideas that can be generated in a particular place and historical moment, and they also affect the general level of the countries' scientific production. In this regard, the conventional wisdom has basically emphasized the huge existing gap in the knowledge output of countries (Davidson Frame et al. 1977; Braun et al. 1988), which seems to result from differences in the level of economic development, particularly in terms of the existing disparities between broad dichotomous categories like core and peripheral countries, or the global North and South (Sagasti and Alcalde 1999).

In addition, and given that the preferred approach to measure the production of scientific knowledge is the analysis of publications in international refereed journals indexed in databases like ISI, Scopus, Medline, etc., some authors have suggested the existence of a bias against many countries in terms of their actual contribution to science (Sancho 1992; Gibbs 1995; Narvaez-Berthelemot and Russell 2001; Van Leeuwen et al. 2001). Hence, the thesis that linguistic aspects could presumably erect a barrier to the diffusion of the works made by scientists from countries whose language is not English (Hwang 2005). Moreover, among the contextual factors to be considered, the centrality of economic factors should not overshadow the importance of the political aspects, which have been mainly considered in case studies on the scientific production of countries (Quesada-Allué and Gitlin 1995; Martin 1999; Cardona and Marx 2005), since the degree of financial support for scientific activity ultimately depends on the convictions about its significance held by the incumbent political elites.

Despite the preceding considerations, there are no studies that analyze how these factors together affect the countries' scientific productivity, examining specifically whether their effects operate in the same way across different scientific disciplines. This it is the goal of this paper, which does not analyze science as a mere aggregate of disciplines, but considers that, among them, there is an irreducible heterogeneity in terms of the human, material, and organizational resources that they use to operate. To this end, the paper is organized as follows. In the next section, I describe the hypotheses of the study. Then, I discuss its methodological aspects. The following section presents the results obtained. Finally, in the concluding section, I summarize the main findings.

Determinants of the scientific productivity of countries

As already noted, the preferred form to evaluate scientific production, in terms of the quantification of its existence and impact, is through databases indexing publication data from scientific refereed journals that respond to standards of quality deemed acceptable by the own members of the scientific community. The inequality in the countries' output is a significant fact that highlights the difference of resources that each country can allocate to scientific research activities (Braun et al. 1988; Davidson Frame et al. 1977; Sagasti and Alcalde 1999; Shrum and Shenhav 1995), which raises the relevance of economic factors, and particularly that of economic development.

The generation of scientific knowledge appears as characterized by a core-periphery division, which exhibits a large accumulation of resources and prestige by the developed countries and whose logic of operation tends to be self-perpetuating to the detriment of the less developed countries (Canagarajah 2002; Dahdouh-Guebas et al. 2003; Gaillard 1994; Schott 1998). Although, in the 1950s and 1960s, there was a wave of creation of national institutes dedicated to supporting the development of science and technology (Drori et al. 2003), huge differences between countries in the resources available for such activities exist. These disparities seem to be related to the degree of economic development, conceptualized as a country's average per capita level of wealth generation.

In order to conduct scientific research, it is not enough to count on a critical mass of researchers with an adequate level of education and training in their areas of expertise, something that many less developed countries already possess, but these researchers must also have the material resources necessary to carry out their tasks. The access to the appropriate equipment, instruments, and other inputs required to perform scientific research tends to be more difficult for those who reside in less developed countries (Gaillard 1994; Vessuri 1997). Consequently, in consonance with the empirical findings of the literature (Cole and Phelan 1999; Schofer 2004), it can be expected that

H1 The economic development of a country has a positive effect on its output of scientific knowledge.

Nevertheless, the mere per capita wealth of a country may not be the only relevant economic factor for the production of scientific knowledge. If the argument accounting for this knowledge generation is based on the availability of financial resources, then the size of the economy could be as important as its development level (Davidson Frame 1979), something already pointed out by Derek de Solla Price (1969). Some poor countries with large economies are in fact dual economies in which a technologically advanced economic sector coexists with a backwards and typically informal one. In such cases, the State is able to allocate funding to scientific activities, under the belief that this can be useful to advance the country's technological capability, thus contributing to its economic development and welfare. In addition, large countries (even those with low GDP per capita) usually give importance to their military budget. Since R&D military spending may have a beneficial spill-over effect on the development of science and technology, there could be a positive relationship between size and scientific productivity. The paradigmatic example of the link between defense-related funding and the expansion of science is the United States, where military spending has influenced not only hard sciences like physics, but also the social sciences (Rappert et al. 2008; Smith 1991).

Of course, the size advantage becomes even clearer in the case of wealthy economies. For instance, the total budget of the National Institutes of Health (NIH), the medical research agency of the United States, was in 2005 larger than the GDP of 142 countries (Suber 2006). Therefore, the next hypothesis is that

H2 The size of a country's economy has a positive effect on its output of scientific knowledge.

Yet the countries' degree of participation in the generation of scientific knowledge at the international arena is also influenced by noneconomic factors (Inönü 2003). Since this participation is typically measured by publications indexed in international scientific databases, whose great majority of journals are published in English, linguistic factors should also be considered. Although many publications of diverse countries whose official tongue is not English are published in this language, the linguistic bias can marginalize an important part of the scientific production published in other languages, which is a negative aspect of the so-called linguistic imperialism (Phillipson 1992) that also contributes to intensify the academic dependency between the center and the periphery (Alatas 2003)—a form of epistemic colonialism that can also affect other developed countries whose language is not English, generating a sort of periphery within the very core of the economic world system.

The linguistic barrier combined with the national barrier is associated with the conformation of two types of scientific literature: one oriented to domestic diffusion and the other, to the international one (Hicks 2004). For some authors, the recognition that counts is the one obtained in the international arena of scientific knowledge; but for those scientists from countries whose official language is not English, the possibilities of publishing in this arena may be negatively affected by the linguistic barrier (Swales 1987; Hwang 2005; La Madeleine 2007). This obeys to the fact that the criteria to judge the quality of academic papers in top tier journals published in English are not strictly of a substantive nature, but include formal aspects like the author's stylistic and grammar competence. So, it can be hypothesized that

H3 The countries with English as official language have greater production of scientific knowledge than the rest of the countries.

Since its beginnings, modern science was linked to the broader political environment, which suggests the necessity of considering political factors as potential determinants of its development. Science presents itself as an activity that seeks to further our knowledge about reality guided by strictly objective methodological principles; but the prestige that it currently enjoys as an authoritative source of knowledge makes it become part of the political arena of society (Jasanoff 2004). Furthermore, investment in scientific and technological activities appears as a sign of national prestige. This explains why many countries support their national systems of science and technology beyond the real economic and social benefits accrued by them (Drori 1993). It is, then, pertinent to consider what is the relation between the level of authoritarianism of a country's political regime and its scientific productivity.

The characterization of a political regime in the authoritarian-democratic continuum is a subject that has raised some attention in the social sciences (Ottaway 2003; Schedler 1998). Political authoritarianism, of which totalitarianism is an extreme form, has been variously defined, but all conceptualizations highlight one particular point: the government's curtailment of citizen's civil and political liberties, which is aimed at restricting dissent. Precisely given their interest in ideological control, authoritarian governments are very attentive to what goes on in the realm of scientific activity.

In fact, diverse case studies have discussed the effect of political authoritarianism on science, demonstrating that, in countries with extreme forms of totalitarianism, the definition of what is normal or acceptable science and what is degenerated science (e.g., the '*entartete Wissenschaft*' during the Third Reich) is made by the political power (Martin 1999). Yet despite regime differences, a totalitarian government can be as interested in promoting scientific activity as its democratic counterparts, and it may have even more discretional power than a democratic government to allocate funds to this end, diverting them from other public objectives. However, some historians of science have suggested that authoritarianism does not constitute a favorable environment for the scientific communities (Beyerchen 1977; Cardona and Marx 2005; Josephson 1996).

Moreover, in relation to the social sciences, whose production at the international arena can suppose the establishment of a link with scientists and institutions of democratic countries and, therefore, a certain level of ideological affinity with them, the effect of authoritarianism could be clearly negative, as the government may seek to restrict the support for disciplines that can inspire dissent with the dominant political ideology (Patel 2009). However, there is also evidence that authoritarian regimes have made extensive use of the social sciences for their own purposes of ideological legitimation (Galaty and Watkinson 2004), but such propagandistic production is typically limited to a domestic literature that remains invisible in international databases. So, it can be expected a negative effect of political authoritarianism on scientific production. To put it in other words,

H4 A government's degree of respect for the civil and political liberties of its citizens has a positive effect on its country's output of scientific knowledge.

There are also other potential factors that may influence the scientific productivity of nations, like religious beliefs—whose importance, though, has been recently downplayed by Schofer (2004)—or the very weight of a country's history of scientific activity. Nevertheless, I consider that (1) the development level and the size of a country's economy (2) the linguistic variable, given the hegemony of English in the international arena of scientific production, and (3) the degree of authoritarianism of the political regime in power are perhaps the most essential aspects in the analysis of the countries' scientific output.

The relevant question that this paper will try to answer, then, is whether their effects are the same or vary across different scientific disciplines. We do know that diverse scientific fields—understood as areas of scientific inquiry defined by their object of study, which in many cases determines its methodological approach—may differ in publication activity and citation habits (Adams 2006; Glänzel and Schubert 2003). But whether, and how, the actual structure of determinants of scholarly output differs between scientific fields is a question that has not received much attention in the literature. I will therefore explore this issue, without having any hypothesis about what the possible differences could be. To this end, I have selected a wide sample of different scientific fields of study, excluding the humanities and professional fields.

Data and methods

In order to test the aforementioned hypotheses, the variable scientific productivity was operationalized by the number of citable documents (articles and reviews) published in journals indexed in the SCOPUS database during the year 2009 (SCImago 2011). I have selected SCOPUS over alternatives like the Science Citation Index (SCI) and Social

Sciences Citation Index (SSCI) because of its greater coverage of both number and international base of the journals (Bosmen et al. 2006).

The number of journals indexed by SCOPUS in each discipline or combination of disciplines under analysis is the following: (1) Medicine (I took the category 'miscellaneous', which includes prestigious journals from many subdisciplines): 1,579 journals, of which 385 are not published in English (this figure also includes journals that publish original articles in English as well as in other languages); (2) Chemistry: 534 (60 not published in English); (3) Physics and Astronomy: 531 (24 not published in English); (4) Mathematics: 839 (63 not published in English); (5) Economics, Econometrics, and Finance, 563 (59 not published English); (6) Sociology and Political Science, 214 (33 not published in English); (7) Agricultural and biological sciences, 1,585 (233 not published in English); and (8) Neurosciences, 304 (22 not published in English). As it can be observed, in most cases, except perhaps in medicine, a very small proportion of journals is published in languages other than English, which renders valid the inclusion of a linguistic variable to test if authors working in non-English speaking countries have difficulties in publishing in a collection of journals overwhelmingly dominated by this language.

A problem that appears when attributing authorships of articles to countries is that of multiple authors (Verbeek et al. 2002). To deal with it, I used the method of normal count (i.e., one authorship to each coauthor, regardless of their number). Although widely used, some authors consider this method as inappropriate, since it could inflate the productivity of countries whose scholars tend to collaborate more. However, others studies have also found that it is greatly correlated with other methods like fractional count, in which credit for one paper is attributed proportionally to the number of coauthors (Kalyane and Vidyasagar Rao 1994). In any case, and even admitting that the chosen method is not the ideal one, I used it for reasons of data availability.

Economic development was operationalized by Gross Domestic Product (GDP) per capita. For the economy's size, the GDP was taken. The values of these two variables were expressed as natural logarithms. In order to take into account the existing delay between the beginning, completion, and effective publication of a research work, these independent variables are lagged 5 years. Therefore, the data correspond to the year 2004, and the source is the International Monetary Fund (2007) database. This lag period is consistent with that reported in several research articles on scholarly publication delays (Trivedi 1993; Bradlow and Wainer 1998). It must however be pointed out that taking 5 years or somehow shorter or longer period to adequately capture the effect of the explanatory variables on the number of publications is not something that could significantly affect the results obtained, since the values of the time series are strongly autocorrelated. Country language was operationalized by a dummy variable coded 1 if English is a country's official language and 0, otherwise. Data source for this variable is the Central Intelligence Agency's (2009) Factbook.

Political authoritarianism has been operationalized through one of the governance indicators elaborated by the World Bank (Kaufmann et al. 2006): voice and accountability, which measures the level of the governments' respect for civil and political liberties (e.g., freedom of association, freedom of expression, freedom of religion, free press, free elections, etc.). In turn, this indicator is constructed from several indicators of different sources (e.g., Freedom House) that are weighted and combined in a standardized index whose values range between a minimum of -2.8 and a maximum of 2.6. A greater value of the indicator means a greater respect for civil and political liberties.

Finally, in order to take demographic proportionality into account, I controlled for the effect of the countries' population size, since it can be presumed that the larger a country's population, the larger its scientific knowledge output. The source of population size (in million units) is also the IMF database. Countries considered too small (less than 1,000,000 inhabitants) were excluded from the analysis, as well as those for which data were not available for all variables (e.g., Cuba, Serbia). The final sample includes 147 countries (see Appendix).

Given the discrete nature of the dependent variable and the problem under analysis, a count model was estimated (Greene 1997). This form of specifying the model is much more adequate than regression by ordinary least squares, since the distribution of the dependent variable follows the formal characteristics of count models (Cameron and Trivedi 2003)—i.e., a discrete positive variable, whose distribution is skewed to the left with a large number of units of analysis with zero or minimum values. Consequently, I opted to initially estimate the most simple functional form for this type of analysis, the Poisson model, whose density function is:

$$f(y_i) = \frac{e^{-\mu_i} \cdot \mu_i^{y_i}}{y_i!}$$

The usual parameterization of μ_i is a function of the regressors of interest that follows a log-linear specification:

$$ln\mu_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_k x_{ki}$$

The sign of the parameters β_i in the regression will indicate whether the data supports the hypotheses under study.

However, the Poisson model has the very restrictive assumption of equidispersion, which requires y_i's mean and variance to be equal. When this does not occur, which is often the case because the variance is usually larger than the mean (overdispersion), other models should be utilized to estimate the parameters of interest. The most common alternative is the negative binomial distribution model, whose probability density function has the form:

$$f(y_i) = \frac{\Gamma(y_i + \theta)}{\Gamma(\theta) \cdot y_i!} \cdot \frac{\mu_i^{y_i} \cdot \theta^\theta}{(\mu_i + \theta)^{yi+\theta}}$$

in which Γ denotes the gamma function and θ is the model's dispersion parameter, which must also be estimated.

Following Cameron and Trivedi's (1996) recommendation, both regression models, Poisson and negative binomial, were estimated using the software STATA 10.0; and a likelihood ratio test was carried out under the null hypothesis that the dispersion parameter in the negative binomial model equals zero. The results obtained in the test led to reject the null hypothesis, indicating that the Poisson model is not adequate in this case. Therefore, I only report the results from the negative binomial regression.

Results and discussion

Table 1 reports the correlation coefficients for the variables. As it can be readily appreciated, the output of certain disciplines in highly correlated, and from this we can expect that they will have similar determinants. Mathematics, physics and astronomy, and chemistry have correlations coefficients over 0.95. The output of the disciplines dealing with biological subjects (medicine, neurosciences, and agricultural and biological sciences)

Table 1 Correlation Matrix

	Mathematics	Physics and astronomy	Chemistry	Agricultural and biological sciences	Neuro-sciences	Medicine	Economics	Sociology and political science	Ln GDP	Ln GDP per cap.	Population	English	Civil and political rights
Mathematics	1	0.98	0.95	0.96	0.89	0.94	0.85	0.80	0.63	0.39	0.53	0.08	0.29
Physics and astronomy		1	0.98	0.92	0.83	0.88	0.79	0.71	0.61	0.35	0.60	0.05	0.24
Chemistry			1	0.89	0.74	0.83	0.68	0.61	0.61	0.32	0.72	0.05	0.22
Agricultural and biological sciences				1	0.94	0.97	0.90	0.87	0.62	0.38	0.51	0.14	0.32
Neurosciences					1	0.97	0.98	0.96	0.50	0.35	0.27	0.16	0.29
Medicine						1	0.96	0.93	0.56	0.37	0.42	0.16	0.29
Economics							1	0.99	0.49	0.36	0.21	0.19	0.31
Sociology and political science								1	0.44	0.33	0.16	0.21	0.29
Ln GDP									1	0.76	0.35	−0.06	0.51
Ln GDP per cap.										1	−0.04	−0.06	0.70
Population											1	0.08	−0.06
English												1	0.11
Civil and political rights													1

are also highly correlated—among them, the weakest correlation, between neurosciences and agricultural sciences, is 0.94. Lastly, economics and sociology and political sciences have also a high correlation coefficient (0.99). Interestingly enough, the output in the social sciences is highly correlated with that in neurosciences, medicine, and agricultural and biological sciences. Regarding the independent variables, size of the economy is moderately correlated with scientific productivity in all cases, with the largest correlation coefficient in the case of mathematics (0.63). The correlation between the dependent variables and GDP per capita is lower, ranging between 0.39 and 0.32. In the case of respect for civil and political rights the correlation with the dependent variables is even lower (between 0.31 and 0.22). Finally, the correlation coefficients between the linguistic variable and the output in the selected scientific disciplines is quite low. Next, I will analyze the results of the negative binomial regression models.

In the first place, I will consider the results for the output in the selected social sciences: sociology and political science, on the one hand, and economics, on the other, which are reported in Table 2. As it can be observed, the results are very similar in both cases. For each scientific field, I consider three regression models. The first one includes only the economic variables and the countries' population as control variable. Consistently with the predictions of hypotheses 1 and 2, both the economy's level of development and its size have a positive and statistically significant effect on scientific production in these disciplines. The statistical significance of the economy's size is very high in two cases. The coefficients of the demographic variable are negative, but devoid of statistical significance. Model 2 adds the linguistic variable, whose effect is positive and highly statistically significant, supporting hypothesis 3 that predicts greater scientific productivity for countries whose official language is English. It must also be indicated that the addition of the linguistic variable constitutes a statistically significant improvement of model fit relative to model 1, according to the likelihood ratio test, in the cases of both scientific fields. Finally, model 3 incorporates the political variable, respect for civil and political liberties. This produces an important change: the coefficients of the economic development variable diminish and lose statistical significance in both cases. On the other hand, the political variable appears with a positive and highly significant effect. In agreement with hypothesis 4, the countries whose governments show more respect for the civil and political liberties of their citizens have greater scientific productivity in the disciplines under analysis. The effects of English as official language and size of the economy are the same as in model 2, while the population variable continues having a negative coefficient that lacks statistical significance. The likelihood ratio test indicates that adding the political variable improves the model fit with respect to model 2, in both cases. These results are very important, since they demonstrate that, once the government's level of authoritarianism has been controlled for, the countries' development level loses statistical significance in terms of its effect on scientific production, thus contradicting hypothesis 1.

For the three models, I have estimated Cragg and Uhler's pseudo R^2, a coefficient ranging between 0 and 1 that measures the improvement of fit of the model with covariates relative to a base model with only the constant term. A value of 1 means that the full model predicts the dependent variable perfectly. In all cases, the obtained values were high, indicating a good fit of the specified model, with model 3 being the highest of them with 0.84 for sociology and political science and 0.83 in the case of economics. Overall, these results suggest that scientific production in the social sciences seems to have a common structure of economic, political, and linguistic determinants, regardless of discipline or subdiscipline.

Table 2 Results of binomial regression (sociology and political science, economics)

Independent variables	Sociology and political science			Economics, econometrics and finance		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Constant	−21.4343 (1.5025)	−21.2517 (1.4640)	−19.0596 (1.3660)	−21.8383 (1.5980)	−22.17952 1.58023	−20.6364 (1.5546)
Log GDP per capita	0.3496*** (0.0937)	0.3754*** (0.0908)	0.0117 (0.1007)	0.2419** (0.0918)	0.2621** (0.0900)	0.0357 (0.0971)
Log GDP	0.8491*** (0.0824)	0.8269*** (0.0797)	0.8550*** (0.0707)	0.9406*** (0.0875)	0.9412*** (0.0858)	0.9520*** (0.0812)
English	–	0.6239** (0.2201)	0.4598* (0.1913)	–	0.6389** (0.2195)	0.4993* (0.2060)
Civil and political liberties	–	–	0.7490*** (0.1288)	–	–	0.5318*** (0.1215)
Population	−0.0004 (0.0007)	−0.0005 (0.0007)	−0.0002 (0.0006)	−0.0002 (0.0007)	−0.0003 (0.0007)	−0.0000 (0.0006)
Dispersion parameter	0.8815 (0.1490)	0.8081 (0.1394)	0.5769 (0.1064)	1.0340 (0.1529)	0.9574 (0.1435)	0.8294 (0.1272)
Log likelihood	– 442.1363	−437.9857	−423.4943	−562.2633	−557.7763	−549.26
Pseudo R^2 (Cragg & Uhler)	0.80	0.81	0.84	0.80	0.81	0.83

Standard errors in parentheses

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Table 3 reports the results for mathematics, physics and astronomy, and chemistry, disciplines whose output is highly correlated. Hence, similar results can be expected and this is what has been found, although minor differences exist. The coefficients of model 1 are positive in all cases, although the level of GDP per capita is most significant in the cases of mathematics and physics and astronomy. So far, the results support hypotheses 1 and 2. The first result that is in opposition to what could be expected appears in the regression of model 2, which constitutes a statistically significant improvement of model fit in relation to model 1 for the three cases. The economic variables maintain their positive and statistically significant effect, and the positive effect of the population control variable acquires certain level of statistical significance except in the case of mathematics. What is interesting is that the added variable, English as official language, exhibits a negative and statistically significant effect, suggesting, in opposition to hypothesis 3, that having English as official language in a country diminishes its scientific productivity in mathematics, chemistry, and physics and astronomy (in this latter case, with a very high level of statistical significance). This finding does not imply that acquiring fluency in written English is not an additional problem for scientists in countries where it is not an official language, but that either this problem has been clearly overcome as a barrier or the discipline's scientific publications do not pay much attention to linguistic style. Finally, in model 3, the added political variable has a negative sign for mathematics and physics and its effect lacks statistical significance in all cases, contradicting hypothesis 4. Also, the GDP per capita diminishes its statistical significance in the case of mathematics and loses it in the case of chemistry. Anyway, this model does not statistically improve the fit over model 2, which is the best of all for three fields under study.

In sum, the relevant results in the three cases are that the effect of the linguistic variable is negative and significant, while both economic variables have a positive as well as statistically significant effect, and the political variable does not seem to be a relevant factor. In all cases, Cragg and Uhler's pseudo R^2 shows rather high values, with 0.80 for mathematics and 0.81 chemistry in model 2.

The results corresponding to medicine (miscellaneous), neurosciences, and agricultural and biological sciences are reported in Table 4. For medicine and agricultural and biological sciences, model 1 only shows one variable with a statistically significant effect, the economy's size, which is in accordance with hypothesis 2, while the lack of statistical significance of the economic development variable contradicts hypothesis 1. However, the two economic variables do exert a statistically significant effect for the output in the neurosciences. Model 2 also has similar results for agricultural and biological sciences and medicine, showing that the linguistic variable does have a positive and statistically significant effect, consistently with hypothesis 3. This model represents a significant improvement of fit in relation to the previous one. In the case of neurosciences, the effect of the linguistic variable lacks statistical significance. Also, the model fit does not improve relative to model 1. The addition of the political variable in model 3 shows different results for all these disciplines. In the agricultural and biological sciences, respect for civil and political rights is positive and significant, supporting hypothesis 4, while the linguistic variable loses statistical significance and the effect of the GDP per capita is negative and statistically significant, a finding that contradicts hypothesis 1. For this discipline, model 3 improves the fit relative to model 2. In the case of the productivity in medicine, the respect for civil and political rights variable is also positive but has lower statistical significance ($p < 0.10$) than in the case of agricultural sciences. The linguistic variable retains statistical significance, while the effect of GDP per capita becomes negative but is not significant. The fit of this model, though, does not constitute a statistically significant

Table 3 Results of binomial regression (mathematics, chemistry, and physics and astronomy)

Independent variables	Mathematics			Chemistry			Physics and astronomy		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Constant	−20.9906 (1.6481)	−21.054 (1.6188)	−21.118 (1.6513)	−20.6836 (1.5882)	−20.5323 (1.5650)	−20.4720 (1.5783)	−18.5854 (1.7528)	−19.0175 (1.7148)	−19.1480 (1.7306)
Log GDP per capita	0.3365** (0.1174)	0.3305** (0.1114)	0.3485* (0.1451)	0.2384* (0.1169)	0.2385* (0.1110)	0.2113 (0.1426)	0.3559** (0.1450)	0.3644** (0.1320)	0.4239* (0.1808)
Log GDP	0.9389*** (0.0944)	0.9480*** (0.0923)	0.9446*** (0.0940)	0.9696*** (0.0923)	0.9675*** (0.0903)	0.9742*** (0.0928)	0.8575*** (0.1054)	0.8788*** (0.1016)	0.8643*** (0.1062)
English	–	−0.7067** (0.2460)	−0.7036** (0.2468)	–	−0.6724** (0.2424)	−0.6824** (0.2441)	–	−1.1363*** (0.2825)	−1.1421*** (0.2837)
Civil and political liberties	–	–	−0.0309 (0.1587)	–	–	0.0456 (0.1510)	–	–	−0.0918 (0.1884)
Population	0.0009 (0.0008)	0.0012 (0.0008)	0.0012 (0.0008)	0.0013 (0.0008)	0.0016 (x) (0.0009)	0.0016 (x) (0.0009)	0.0015 (0.0010)	0.0020 (x) (0.0011)	0.0021 (x) (0.0011)
Dispersion Parameter	1.4296 (0.1716)	1.3679 (0.1652)	1.3679 (0.1651)	1.4052 (0.1620)	1.3510 (0.1565)	1.3504 (0.1564)	1.9319 (0.2162)	1.7939 (0.2025)	1.7922 (0.2023)
Log likelihood	−775.9396	−772.3213	−772.3023	−818.7229	−815.343	−815.2976	−848.8597	−842.3349	−842.2154
Pseudo R^2 (Cragg & Uhler)	0.79	0.80	0.80	0.80	0.81	0.81	0.73	0.76	0.76

Standard errors in parentheses

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$; (x) $p < 0.10$

Table 4 Results of binomial regression (agricultural and biological sciences, neurosciences, and medicine)

Independent variables	Agricultural and biological sciences			Neurosciences			Medicine (miscellaneous)		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Constant	−17.1382 (1.1170)	−17.3487 (1.1151)	−16.1825 (1.0456)	−23.3860 (1.4893)	−23.3702 (1.4905)	−22.0337 (1.4483)	−16.7719 (1.3321)	−17.0473 (1.3360)	−16.4467 (1.3568)
Log GDP per capita	−0.0441 (0.0733)	−0.0281 (0.0732)	−0.3080*** (0.0815)	0.4541*** (0.1009)	0.4590*** (0.1017)	0.1683 (0.1143)	0.0896 (0.0893)	0.1191 (0.0900)	−0.0064 (0.1096)
Log GDP	0.9447*** (0.0643)	0.9449*** (0.0638)	0.9883*** (0.0579)	0.9277*** (0.0846)	0.9247*** (0.0849)	0.9657*** (0.0794)	0.8544*** (0.0773)	0.8516*** (0.0769)	0.8688*** (0.0761)
English		0.3320 (x) (0.1700)	0.2090 (0.1567)		0.1034 (0.2371)	−0.0620 (0.2206)	–	0.4538* (0.2100)	0.3751 (x) (0.2112)
Civil and political liberties			0.5392*** (0.0925)			0.5493*** (0.1286)	–	–	0.2514 (x) (0.1312)
Population	0.0002 (0.0006)	0.0002 (0.0006)	0.0003 (0.0005)	0.0010 (0.0007)	0.0009 (0.0007)	0.0010 (0.0006)	0.0005 (0.0007)	0.0005 (0.0007)	0.0006 (0.0007)
Dispersion parameter	0.6996 (0.0794)	0.6832 (0.0777)	0.5675 (0.0663)	0.9445 (0.1466)	0.9466 (0.1468)	0.8159 (0.1312)	1.0211 (0.1185)	0.9936 (0.1155)	0.9727 (0.1134)
Log likelihood	−920.0855	−918.0964	−903.5633	−551.0039	−550.9073	−542.8357	−815.4399	−812.9673	−811.2199
Pseudo R^2 (Cragg & Uhler)	0.87	0.87	0.89	0.84	0.84	0.86	0.81	0.82	0.82

Standard errors in parentheses

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; (x) $p < 0.10$

improvement in relation to model 2. For the neurosciences, model 3 does improve significantly the fit over the other models. The effect of respect for civil and political rights is positive and highly significant, again supporting hypothesis 4, and the results for the other variables remain basically unchanged except for the economic development variable that loses statistical significance.

In all cases, Cragg and Uhler's pseudo R^2 coefficients for the three models are also high, with a value of 0.82 for model 2 in medicine, 0.86 for model 3 in neurosciences, and 0.89 for model 3 in agricultural and biological sciences.

Furthermore, these findings are robust to using an alternative indicator of economic development, the log of GDP per capita adjusted by purchasing power parity (PPP), also taken from the IMF database. The only minor variations are that the control variable population has statistical significance in model 1 (physics and chemistry) and model 2 (neurosciences), while the log of the GDP per capita adjusted by PPP is significant in model 3 (chemistry and neurosciences) and medicine (model 2). In all cases, such differences do not alter the general findings summarized below.

The results of the regression models demonstrate that the effect of different economic, linguistic, and political determinants is contingent upon the scientific discipline under analysis. In the case of the so-called exact sciences (mathematics, physics, and chemistry), economic factors are of central importance, whereas, contrary to what could be expected according to the literature, the 'linguistic imperialism' thesis does not seem to affect the production of countries whose official tongue is not English. The level of political authoritarianism in terms of the government's respect for civil and political liberties does not appear relevant to scientific activity. It would seem that all countries seek to participate in these activities, whose productivity level is only affected by the availability of financial resources, which can be explained basically from economic variables.

Scientific productivity in the social sciences obeys to a different logic. It is true that the availability of financial resources is a central factor, but this seems more dependent upon the economy's size than upon its level of economic development, which lacks statistical significance. In these disciplines, the political factor is indeed of importance, as the government's degree of authoritarianism has a negative and significant effect on scientific productivity. Linguistic imperialism is not a myth in the social sciences. Once other relevant factors are controlled for, the variable English as official language has a positive and significant effect on scientific productivity. The fact that the linguistic and political variables play a central role in the countries' scientific production in social sciences is not unexpected. This study suggests that linguistic proficiency in the dominant language is important for social scientists, although this finding could perhaps be caused by a potential coverage bias in the social science literature by international databases. In any case, if publishing in international journals is important for the members of the scientific community, it is clear that social scientists from non-English speaking countries are at a disadvantage in this regard.

Another interesting finding is that the pattern of determinants for scientific production in medicine is very similar to that of the social sciences. In the case of agricultural and biological sciences, the results also similar to those of economics, but here the economic development variable appears with a negative and statistically significant effect in model 3, which is difficult to interpret. Perhaps, developing countries dedicate their scant economic resources for scientific research to issues of agriculture, due to the fact that their economies are mainly based on the production of primary goods, which in most cases does not cover adequately the needs of their own population. For the neurosciences, the positive effect of respect for civil and political rights suggests that this area of study is not a top priority of authoritarian governments.

In some disciplines, not having English as native language appears to be an obstacle for visibility in international databases for scientists from certain countries (even when these databases have a very small percentage of journals published in languages other than English). This seems not very surprising in the case of the social sciences, which appear to be more oriented to domestic topics, thus generating an important "national literature" that could not be adequately covered in scientific databases. However, the linguistic imperialism thesis also seems valid for disciplines like medicine, and agricultural and biological sciences. This is perhaps related to the fact that, in these disciplines, there is also a large number of researchers who publish their work in local outlets. In other words, it could be the case that, per force, scholars in the exact sciences and other disciplines like neurosciences do need to became fluent in English to publish in scientific journals, while those in other scientific disciplines have other options. A particular case is medicine, which is as much a scientific field of inquiry as a field of professional work. There are many magazines targeted at medicine practitioners who are not, nor need to be, proficient in foreign languages. In many developing countries, most publications in medicine are made in these magazines, which are not indexed in international databases, rather than in scientific outlets. Of course, the dichotomy between practitioner-oriented and scholarly-oriented journals is also found in journals published in English-speaking countries (and journals in English basically targeted at practitioners could even be indexed in international scientific databases), but this distinction does not overlap with the domestic versus "international" literature divide, whose basis of differentiation is basically the language of publication (Hicks 2004).

Moreover, an important point is the international mobility of scientists (e.g., doctoral studies, post-doctoral jobs, etc.). Scientists working abroad establish personal bonds and collaboration networks with other scientists of their host country, hence obtaining "scientific social capital", which contributes to increase their scientific productivity when returning to their home countries (Jonkers 2010). As international mobility differs across disciplines (Calibano et al. 2011), it is possible that those disciplines with greater international mobility between members of national scientific communities, specifically mobility to English-speaking host countries, have greater scientific productivity in English-language scientific journals than those disciplines with less international mobility. This could explain the irrelevance of the linguistic factor as determinant of productivity in certain scientific disciplines. For instance, taking doctoral studies in the United States as an example of scientific mobility (National Science Board 2012), the number of foreign doctoral students in physics during the period 1989–2009 was 6,068, greater than that of all the social sciences combined for the same period (5,205).

Similarly, the finding that political authoritarianism does influence scientific productivity at the international arena in the social sciences could be explained by the fact that these disciplines deal with topics that could require some form of censorship on the part of governments with an authoritarian bent. Also, given the importance of the domestic literature in these fields (local journals, books), the social scientists' degrees of freedom from the incumbent government are very limited. Either they are with the regime, or they do not engage in research at all. But what is the reason why political authoritarianism has no effect on the scientific output in fields like physics and astronomy, mathematics, chemistry, but it does bear some impact in medicine, neurosciences, and agricultural and biological sciences? It could be speculated that the former areas are of interest for authoritarian governments as much as for democratic governments, while medicine and the other fields are not perceived as much worthy of research funding by authoritarian political regimes. There is, however, some evidence that physics is a discipline that has received particular support within authoritarian regimes as the Soviet case exemplifies (Kojevnikov 2004), yet further information of other national cases is needed. Nevertheless, the demonstration that, ceteris paribus, political factors still play a role in the creation of scientific knowledge, in terms of visibility in international databases, is something that merits further scholarly attention.

It could be argued that this international comparison among different sciences is not completely appropriate, since the dimension of national productivity in the social sciences is not accurately captured by international databases (Archambault and Larivière 2010). Unlike the exact and national sciences, disciplines like sociology have local, indigenous character (Sztompka 2009). While this observation is correct, it is also evident an interest of social scientists working in non-English speaking countries to reach a wider international audience by participating in the international arena represented by the journals in English (Dwyer 2009). In any case, and with this limitation in mind, I think that exploring international visibility for the social sciences and comparing the findings to those of other scientific fields gives us important information about how scientific effort is influenced by economic and political domestic characteristics.

Conclusion

To sum up, this study shows that the resources that each country mobilizes for research activities in what is regarded as "international science" is contingent upon the different scientific disciplines. As suggested by the pseudo R^2 coefficients, the specified models seem to have a good fit with the data, given the selected functional form for the regression.

An important finding is that political aspects, which were rarely analyzed in cross-national comparisons of scientific productivity, are found to be a significant determinant of scientific output, but only in selected disciplines like the social sciences. A less surprising result is that, in consonance with the literature, economic factors are relevant in scientific research output, but it stresses the need to distinguish between an economy's level of development and its size, which is the common factor for productivity in all fields of inquiry. The results also demonstrate that, despite the attention received in recent years, the linguistic imperialism thesis does not seem to have predictive power for scientific productivity in several fields, even showing that in some of them the statistically significant effect of English runs, strangely, in the direction opposite to that predicted by this thesis.

Acknowledgments The author is grateful to the anonymous reviewers for their helpful comments and suggestions.

Appendix—List of Countries

Afghanistan, Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bangladesh, Belarus, Belgium, Benin, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Canada, Central African Republic, Chad, Chile, China, Colombia, Democratic Republic of Congo, Republic of Congo, Costa Rica, Côte d'Ivoire, Croatia, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Estonia, Ethiopia, Finland, France, Gabon, Gambia, Georgia, Germany, Ghana, Greece, Guatemala, Guinea, Guinea-Bissau, Haiti, Honduras, Hong Kong, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Kyrgyz Republic, Lao, Latvia, Lebanon, Lesotho, Liberia, Libya, Lithuania, Macedonia, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mauritius, México, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nepal, Netherlands, New Zealand, Nicaragua, Níger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Russia, Rwanda, Saudi Arabia, Senegal, Sierra Leone, Singapore, Slovak Republic, Slovenia, South Africa, South Korea, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syrian Arab Republic, Taiwan, Tajikistan, Tanzania, Thailand, Togo, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, Uganda, Ukraine, United Arab Emirates, United Kingdom, United States, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe.

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