Patterns of Knowledge Diffusion via Research Collaboration on a Global Level

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Abstract
The evolution of the patterns of collaborative strategies plays an important role in the social construction of science to design efficient research policies and to support the production of knowledge. As international research landscape is clearly undergoing continued structural change, we aim to analyze dynamics in collaboration strategies/patterns at the global and disciplinary level, and to investigate whether countries are collaborating more diversely within their region compared to outside their own region using different approaches. We found that internationalization in science is growing in all disciplines. The number of countries in the global network establishes stronger partnerships, forming tightly knit groups and spreading influence more widely among countries with a preference to collaborate within the region instead of collaborating with out-region countries. We believe that these results, though preliminary, have significant implications for the design of programmes and alliances.

Introduction
Science is being characterized by the exponential growth in publications and the rise of team science scholars. This trend of growth in the size of research teams have an effect on evaluative assessment, which are becoming more significant in all subject fields (Bozeman & Boardman 2014; Wuchty, Jones, & Uzzi, 2007). Individual and institutional research assessments supported by metrics have a powerful “pull” effect on scientists competing intensely within an economy of reputation seeking to maximize their own research output and impact (Hennemann & Liefner, 2015). At the same time the evolution of the patterns of collaborative strategies, especially international collaboration, plays an important role in the social construction of science to design efficient research policies and to support the production of knowledge (Coccia & Wang, 2016). The availability of local skills and capacities are central to the development trajectories of regions incorporating science, technology, and innovation in their national development agendas for economic growth (UNESCO, 2015).

It has been argued that “the best science comes from international collaboration” and “scientific research is entering a new age, driven by international collaborations” (Adams, 2013, p. 557). As scientific collaboration networks are expanding and characterizing the social construction of science (Adams, 2012), the growth of international collaboration has been studied to investigate collaboration at different levels and to inform scientific policy makers who evaluate the scientific output of their countries. Scientific policy makers in developed countries are definitely aware of the importance and benefits of research collaboration, with many countries providing specific funding to support large-scale collaborative research projects (Corley, Boardman, & Bozeman, 2006). The study of collaborative strategies in science might provide detailed patterns and inform science policy makers. However, little has been
known about how collaborative strategies at the global and disciplinary level have evolved in the last decade.

The growth of international collaboration has been analyzed at the global, regional, and disciplinary level in previous studies. Wagner and Leydesdorff (2005), for instance, found that the principle of the preferential attachment might explain that countries with more collaboration are able to attract more collaboration. Indeed, a few countries dominate the knowledge flows at the global level, even when the global network has widened to include a much greater number of countries (Leydesdorff et al., 2013). At the regional level, the growth of international collaboration moves science system away from institutional collaboration, with stable and strong national collaboration. For example, the growth of publications in major European systems is almost entirely attributable to internationally co-authored papers. This growth is not only a function of state and EU promotion and funding but also reflects individual scientist’s pursuit of reputation and resources (Kwiek, 2020). The globalization of science does not seem to have evolved uniformly across all countries and regions, as historical, geographical, and economic factors play a key role (Chinchilla et al., 2019; Geuna, 2015; Sherngell, 2013). Knowledge and capabilities have been conceptualized as geographically sticky, since tacit knowledge and abilities are a result of a workforce and not easily transportable. Research collaboration with scientists from other regions could allow countries to upgrade their academic capacity and respond to unique societal and economic challenges more readily (Fitzgerald et al., 2021; Frenken & Boschma, 2007; Hidalgo et al., 2007).

Yet, this existing body of research usually focuses on more advanced countries —many countries fall outside this taxonomy and are therefore understudied. To better understand the dynamics of the global system of science, we must move to a more comprehensive analysis. As international research landscape is clearly undergoing continued structural change with new leaders (in term of size) emerging from all corners of the globe (Fitzgerald et al., 2021), we aim to analyze how this shift in the geographical spread and economic capacities of countries has shaped a reconfiguration of the global collaboration network. Besides, as it is supposed that the corresponding authorship has a distinctive value in the byline of publications (Bu et al., 2019; Huang et al., 2011), we want to study different roles in the integration of new countries in the global network, namely leading or supporting collaborators' role.

**Research objectives**

There are two research objectives of this paper: On the one hand, we aim to identify dynamics in collaboration strategies/patterns at the global level and disciplinary level; on the other hand, we expect to investigate whether countries are collaborating more diversely within their region compared to outside their own region.

**Data and methods**

Data were retrieved from the in-house version of the Web of Science (WoS) maintained at CWTS of Leiden University for articles, reviews, and letters. Each publication in the dataset is clustered as five disciplines according to the algorithm of Waltman and Van Eck (2012). These disciplines are SSH (Social sciences and humanities), BIO (Biomedical and health sciences), PHY (Physical sciences and engineering), LIF (Life and earth sciences), and MAT (Mathematics and computer science). National/Regional-level collaborations were collected from 12,187,856 distinct publications retrieved for
the 2008-2017 period, yielding connections among 216 countries. Among these documents, 3,114,463 were internationally co-authored; this is 25.5% of the total. Document metadata was used to extract author affiliation data for each document. These data allowed for the construction of networks on the bases of collaboration (i.e., co-authorship between countries on a given document). We study three overlapping temporal periods (2008-2011, 2011-2014, and 2014-2017, respectively) to avoid fluctuations in countries with a very limited amount of data records.

We enrich bibliographical metadata by adding information of research and development expenditure (% of GDP) and researchers in R&D (per million people). As expenditures take time in translating into outcomes, infrastructures, workforce, etc., we calculate the mean average of the previous 4-year-long period for each period under analysis. For example, for the period 2008-2011, we consider expenditures in 2005-2008, and for the period 2014-2017, we consider expenditures in 2011-2014. We analyzed affiliated document using full counting methods for all papers and for leading papers. For each country analyzed, papers were grouped into three mutually exclusive categories, based on the institutional addresses of the authors, named collaborative strategies: 1) papers that only have a single institution (no inter-institutional collaboration), 2) papers that have at least two institutions from the same country (domestic collaboration), and 3) papers that have at least two institutions from at least two different countries (international collaboration).

For the constructed collaboration network, we are particularly interested in these measurements:

- The number of edges: It denotes the number of ties between countries.
- Network density: It allows us to determine the degree of cohesion that exists among the nodes, revealing whether the network has a thick or thin consistency and the extent of connectivity among nations (Wasserman & Faust, 1999).
- The average degree of nodes: It measures the spread of influence across the networks (Hanneman & Riddle, 2005).
- Size of $k$-core: A $k$-core is the maximal subgraph in which each node has at least $k$ connections to other nodes in the subgraph, despite how many links we have outside the subgraph. With this method, the densely connected area can be identified and in order to be included in the $k$-core, a node must have at least $k$ links to other nodes in the $k$-core, regardless of how many other nodes they are connected to outside the $k$-core (Kong et al., 2019).

Besides, we also expect to examine whether countries are collaborating more diversely within their region compared to outside their own region. To this end, we employ the Shannon’s entropy by regions. Specifically, we follow Fitzgerald et al. (2021) and calculate three measurements:

- Within-region entropy: 

  \[
  CE_{in}(i, t) = -\frac{1}{\log(N(t)) - 1} \sum_{j \in J_u} \frac{n_{ij}^{(t)}}{\sum_{j \in J_u} n_{ij}^{(t)}} \cdot \log\left(\frac{n_{ij}^{(t)}}{\sum_{j \in J_u} n_{ij}^{(t)}}\right)
  \]

  where $N(t)$ represents the number of countries in our dataset in the given period $t$.

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1 Some of the 216 countries are not real “countries”. Rather, some are regions/territories. Yet, for the sake of simplicity, we use “country” in the following sections in this paper.

2 Gross domestic expenditures on research and development (R&D), expressed as a percent of GDP. They include both capital and current expenditures in the four main sectors: Business enterprise, Government, Higher education, and Private non-profit. R&D covers basic research, applied research, and experimental development.

3 The number of researchers engaged in R&D, expressed as per million. Researchers are professionals who conduct research and improve or develop concepts, theories, model techniques instrumentation, software of operational methods. R&D covers basic research, applied research, and experimental development.
the number of collaborations between countries $i$ and $j$ in time period $t$, $J_u$ the set of countries in the region of country $i$.

- Outside-region entropy: $CE_{out}(i, t) = -\frac{1}{\log(N(t) - 1)} \sum_{j \in J_o} \frac{n_{ij}^{(t)}}{\sum_{j=1}^{N(t)} n_{ij}^{(t)}} \cdot \log\left(\frac{n_{ij}^{(t)}}{\sum_{j=1}^{N(t)} n_{ij}^{(t)}}\right)$, where $J_o$ the set of countries outside the region of country $i$.

- The proportion of within-region entropy (as a measurement to understand the dynamics of inter- and intra-region collaboration diversity): $C(i, t) = \frac{CE_{in}(i, t)}{CE_{in}(i, t) + CE_{out}(i, t)}$

We also expect to see how the expenditures on R&D of a country affects its performance on international collaboration and within-region collaboration. To this end, we implement two distinct regression models. In the models, we adopt the proportion of internationally collaborative publications and the proportion of within-region Shannon’s entropy as the dependent variable, respectively. For the independent variables, we consider the average R&D investment proportion (among all its GDP between 2008 and 2017) and the number of researchers per one million population in the country. For both models, we use the income level of countries as a control variable in both models.

Yet, we found that the distribution of within-region Shannon’s entropy is highly skewed. To this end, we cannot adopt the raw variable to a regular regression model. Instead, we use the percentile (rank) of this variable in the model in practice. Moreover, for a specific country, if any of the values of two independent variables is missing, we remove this country from our regression analyses. This results in 109 countries/regions remained.

**Results**

**Overview**

Table 1 provides an overview of data for the three periods. All indicators show a growth on international collaboration. The number of internationally collaborative papers has grown at a high rate (71.8%) than the total number of papers (53.4%). At individual level, the number of authors involved in internationally collaborative papers has risen by 81.3% much faster than the number of unique authors at the global level (66.55%). Besides, almost all countries have participated in the global international network as leading or supporting collaborators.

**Table 1. Basic statistics of research collaboration by 4-year periods.**

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<tr>
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<tbody>
<tr>
<td>Number of papers</td>
<td>3846013</td>
<td>4879242</td>
<td>5898173</td>
<td>53.36</td>
</tr>
<tr>
<td>% international collaboration</td>
<td>23.6</td>
<td>25.2</td>
<td>26.5</td>
<td>12.05</td>
</tr>
<tr>
<td>% domestic collaboration</td>
<td>35.2</td>
<td>36.5</td>
<td>36.7</td>
<td>4.11</td>
</tr>
<tr>
<td>% single-authored papers</td>
<td>40.7</td>
<td>38.0</td>
<td>36.7</td>
<td>-9.96</td>
</tr>
<tr>
<td>Number of authors</td>
<td>6352677</td>
<td>8371230</td>
<td>10580467</td>
<td>66.55</td>
</tr>
<tr>
<td>% international collaboration</td>
<td>32.7</td>
<td>34.2</td>
<td>35.6</td>
<td>8.86</td>
</tr>
<tr>
<td>% domestic collaboration</td>
<td>50.7</td>
<td>51.8</td>
<td>52.4</td>
<td>3.37</td>
</tr>
<tr>
<td>% single-authored paper</td>
<td>46.6</td>
<td>43.5</td>
<td>40.1</td>
<td>-14.08</td>
</tr>
<tr>
<td>Number of countries</td>
<td>211</td>
<td>218</td>
<td>227</td>
<td>7.58</td>
</tr>
<tr>
<td>% of leading countries</td>
<td>98.1</td>
<td>96.3</td>
<td>95.6</td>
<td>-2.56</td>
</tr>
</tbody>
</table>

At the disciplinary level, Figure 1 shows that the percentage of internationally collaborative papers has increased around 12% in all disciplines. BIO and LIF present the highest values of growth in contrast with SSH that decrease 2.34%. In domestically collaborative papers, SSH also present a decline followed away from MAT (22.5% and
5.5%, respectively) in favor of increasing proportionally in single-authored papers (26.5% and 0.54%, respectively). The rest of disciplines present difference patterns, decreasing the percentage of single-authored papers in favor of international and domestic papers. Similar patterns are observed in the number of authors involved in distinct collaborative partnerships (Figure 2).

**Figure 1. Evolution of the percentages of papers (A) and authors (B) by collaboration types at the global and disciplinary levels. Temporal periods: 2008-2011, 2011-2014, and 2014-2017.**

**Figure 2. Growth rate of the number of papers (A) and authors (B) by collaborative types at the global and disciplinary levels.**

The number of authors involved in at least one internationally collaborative paper increase significantly especially in SSH and MAT (12.6% and 11.5%, respectively). Considering authors that have been involved in at least one domestic paper, all disciplines show an increase except for SSH (-7.8%), which is the only discipline where the number of authors involved in at least one single-authored paper has risen (5%). Finally, considering the number of countries that at least have been involved in international collaboration as corresponding author, we can observe a descend
especially strong in LIF and BIO and only PHY increase the number of countries acting as corresponding authors in international collaboration. These findings are in consonance with trends observed in previous studies (Coccia & Wang, 2017; Leydesdorff & Wagner 2008; Wagner, Park, & Leydesdorff, 2015).

**Network analysis**

We conducted network analyses to examine whether the network changed as the number of papers increased. Network measures are shown in two levels of aggregation: global and disciplinary level. Table 2 displays a set of basic structural indicators to analyze the structural properties of the global collaboration network. The number of countries linked to other countries has growth in the past decade (8%). According to the UNESCO⁴, there are 193 country members and 11 Associate members. Our findings show that almost all nations and territories have researchers participating in international collaborative networks.

The size of the $k$-core component grew from 99 to 113 countries in a 10-year period. The average degree increases 34%. The average distance across the network is lower than two—a very low number considering the global network as a whole—and it is decreasing in the years examined. Diameter measures the longest distance between a pair of countries. In our study, the diameter is equal to 3 which mean that the distance from one side of the network to the other is small and the network is tightly linked together. Average clustering coefficient is high, which reinforces that the global network is forming tightly knit groups. To a certain extent, the global network is characterized by a high level of clustering and a small average number of steps between countries, which fits with the model of ‘small world (Watts & Strogatz 1998). All these indicators suggest that the network became denser, and that influence and power (in terms of collaboration flows control) were spread more widely among countries at the global level.

**Table 2. Network statistics for the global network science.**

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<tbody>
<tr>
<td>Number of nodes</td>
<td>210</td>
<td>217</td>
<td>227</td>
<td>8.10</td>
</tr>
<tr>
<td>Number of edges</td>
<td>8319</td>
<td>10031</td>
<td>12071</td>
<td>45.10</td>
</tr>
<tr>
<td>Density</td>
<td>0.38</td>
<td>0.43</td>
<td>0.47</td>
<td>24.14</td>
</tr>
<tr>
<td>Average degree</td>
<td>79.23</td>
<td>92.45</td>
<td>106.35</td>
<td>34.23</td>
</tr>
<tr>
<td>Average shortest path</td>
<td>1.63</td>
<td>1.58</td>
<td>1.54</td>
<td>-5.84</td>
</tr>
<tr>
<td>Diameter</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>0.00</td>
</tr>
<tr>
<td>Average clustering coefficient</td>
<td>0.79</td>
<td>0.80</td>
<td>0.81</td>
<td>2.83</td>
</tr>
<tr>
<td>Betweenness</td>
<td>0.003</td>
<td>0.003</td>
<td>0.002</td>
<td>-21.50</td>
</tr>
<tr>
<td>Size of $k$-core component</td>
<td>99</td>
<td>103</td>
<td>113</td>
<td>14.14</td>
</tr>
</tbody>
</table>

At the disciplinary level, Figure 3 shows the growth rate for each indicator over the period studied. We can observe that SSH registers the higher increase in the number of nodes (countries) in international collaboration followed by MAT and LIF. That means that these disciplines are becoming more opened to collaborative partnerships, especially in the case of SSH and MAT. By the other hand, the low increase of PHY and BIO might be explained by the cumulative/historic participation of science. Indeed, these fields are traditionally the most collaborative in research and they are characterized by a high participation of institutions around the world (Glänzel & Schubert 2004; Abramo, D’Angelo, & Murgia, 2013). In all indicators, we can observe a trend already discussed in previous research. The growth of internationally

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⁴ UNESCO https://en.unesco.org/countries/member-states
collaborative papers shows that new members (countries) are entering into the global network and ties among countries are increasing (edges). Greater density of the network and the decrease of betweenness measures suggest that fewer of the communications pass through the leading countries. According to Wagner et al. (2015), this may mean reducing influence for advanced countries, and shifting of power to some “peripheral countries”.

Figure 3. Network statistics by disciplines in the global network.

Collaboration diversity at the geographical level
So far, we have seen as the internationally collaborative papers are still growing in the last decade and that the network is becoming denser and more connected at the global and disciplinary level. The next step in our research is focused on regional level. We want to know how this internationalization is distributed at the geographical level, how it evolves over time and what the main strategies for building ties with partners inside or outside the region at the international level are.

Figure 5A shows the percentage of papers in international collaboration by regions. All regions tend to increase their international participation. Sub-Saharan Africa region shows the highest values in international collaboration followed by Latin America and Caribbean. However, the regions that experienced the highest increases in their international presence are Middle East & North Africa and Europe (Figure 5B).

Figure 5. Percentage of papers by collaborative types and geographical regions.
With country-level data in hand, it is possible to examine regional trends in global science over time to view whether large shifts occur in scientific output and knowledge absorptive capacity over geographic spaces (Wagner, 2018). The heterogeneity of countries in each group in terms of different levels of development and scientific production might affect these results. Then we expect to quantify how countries have changed (or not) their patterns of international collaboration measuring a countries’ diversity of links to collaboration patterns both within their own region and with countries in other regions. As in Fitzgerald et al. (2021), we use the Shannon entropy of the distribution of collaboration partners for each country. The indicator provides values between zero and one. Values closer to one refer to countries that are collaborating evenly with many countries and values closer to zero refers to countries are collaborating with few countries.

For each region, we plot the average proportion of within-region entropy (as a share of total entropy) for each region Figure 6. We observe that Europe & Central Asia shows the highest values of entropy, which means that countries from this region have increase their focus on diverse within-region collaboration. South Asia and North America present a lower diversity of partners. That might be explained by the number of countries in these regions. South Africa and North America are formed by 8 and 3 countries respectively in comparison with the rest of regions. Overall we observed a general declined over time of this tendency except for Sub-Saharan Africa. Countries from this region are intensely collaborating among them.

Figure 6. Within-region entropy (as a share of total entropy) results.

We plot collaboration entropy metrics within and outside of the region for each country by the final time period, with points scaled by the percentage of international collaboration. For example, in Figure 7, we can see that the South Asian countries strongly favor diverse partnerships outside their region; thus, they tend to collaborate more often with countries outside the region. Results show that almost all their production is carried out with international partners except for India, the country with the highest number of publications in the region, with the lowest percentages of internationally collaborative papers and the highest values of within-region collaboration diversity along with Maldives. We might suggest that growth of international publications in these countries is attributable to partnerships outside the region (Figure 7A). Figures 7B and 7C present the evolution over time of these two distinct strategies. We can see changes in some countries intended to opening up with their inter and intra-regional neighbors (for example, Maldives). On the other hand, there are countries that decreases intra-regional collaboration and either remain steady or decrease their inter-regional collaboration (for example, India and Pakistan respectively).
Regression analysis
Table 3 shows the regression result for the proportion of internationally collaborative publications. We see that when the number of researchers per million people and the income level is fixed, the proportion of internationally collaborative publications is negatively and significantly correlated with R&D expenditures. Yet, the number of researchers shows a positive relation with internationally collaborative paper count. Specifically, when other variables are equal, the proportion of internationally collaborative publications will increase 0.4% when there is one more researcher in every one million population.

Table 3. Regression results for the proportion of internationally collaborative publications (R Square=0.35, F=18.53, Sig.=0.00).

|        | Coefficient | Std.  | t      | P>|t|   | [95% Conf. Interval] |
|--------|-------------|-------|--------|-------|---------------------|
| Intercept | 98.767      | 5.307 | 18.611 | 0.000 | 88.245 to 109.290   |
| R&D     | -12.07      | 3.613 | -3.341 | 0.001 | -19.235 to -4.907   |
| Researchers | 0.004       | 0.002 | 2.573  | 0.011 | 0.001 to 0.008      |

Note: “R&D” = Proportion R&D expenditures in the country’s GDP. “Researchers” = Number of researchers per million population. The same below in Table 4.

Table 4. Regression results for the proportion of within-region entropy (R Square=0.05, F=4.84, Sig.=0.00).

|        | Coefficient | Std.  | t      | P>|t|   | [95% Conf. Interval] |
|--------|-------------|-------|--------|-------|---------------------|
| Intercept | 58.429      | 9.877 | 5.916  | 0.000 | 38.846 to 78.013    |
| R&D     | -13.434     | 6.724 | -1.998 | 0.048 | -26.767 to -0.100   |
| Researchers | 0.011       | 0.003 | 3.370  | 0.001 | 0.004 to 0.017      |

Table 4 shows the regression model result for the within-region entropy. We observe that when other variables keep unchanged, the rank of within-region entropy for a country will decrease 12.3% (=13.434 / 109 [=number of countries in the regression model]) if the country increases 1% more GDP on R&D. Such an effect is significant on the 0.05 level. We also find a positive relation between the number of researchers per million population and the rank of within-region entropy for countries as well.
Discussion and conclusions

The evolution of the patterns of collaborative strategies, especially international collaboration, plays an important role in the social construction of science to design efficient research policies and to support the production of knowledge (Coccia & Wang, 2016). This study has shown the main collaborative strategies focusing on the growth of international collaboration over time at global, disciplinary and regional levels using different approaches. International collaboration in science is growing in all disciplines while the share of single-institutions papers is on the decline, which is in consonance with previous studies (Abt, 2007; Larivière et al., 2015). In terms of network analysis, the number of countries participating in the global network has growth establishing stronger partnerships, spreading influence and power more widely among countries and forming tightly knit groups. These findings are in accordance with previous studies showing that, between 1900 and 2005, the number of countries increased from 172 to 194, which represents a growth close to 13%. As long as new countries enter in the global network, this growth is decreasing and suggests that the network is not recreating political structures (Chinchilla et al., 2018; Wagner & Leydesdorff, 2005; Wagner, Park, & Leydesdorff, 2015). Our contribution here lies on the updating of temporal periods of international collaboration compared with other collaborative strategies.

Science policymakers care about the locations of national players as well as the outcomes of research, even when international collaboration seems to respond to the dynamics created by the self-interests of individual scientists rather than to other structural, institutional, or political factors (Wagner & Leydesdorff, 2005). In this study, we use the Shannon entropy as a way to determine the preference of countries to collaborate with other countries within or outside their regions showing that within-region collaboration has increased over time relative to international collaboration. We believe that these results, though preliminary, can shed light on the potential strategic programs or alliances. For example, in the cases that the diversity of collaborators increases more within regions than outside regions, a stronger regional clustering and more institutional cohesion inside the region should be observed. This is the case of Sub-Saharan countries where diversity within regions when compared to diversity between regions is increasingly higher, and the total strength of international collaborations relative to external collaborations also increases. It suggests the formation of localized regional collaboration networks. On the other hand, regions, e.g., Europe, with a high level of within-region partners seems to change the pattern over time, suggesting an opening up of global collaboration networks. However, the heterogeneity or not uniformity in scientific relationships of countries must be considered into each region.

This internationalization presents policy challenges and opportunities. As internationalization of science affects the research performance of countries and, in certain degree, depends on the attractiveness of a partner in the global network, different strategies could be used to attract internal or external partners at convenience at different levels. At the individual level, the choice among forms of collaboration can be influenced by incentives and considerations concerning the organizational research system. For example, a scientist could be encouraged to privilege within-region collaborations because these will favor creation of team spirit within the workplace. In other cases, mechanisms for career advancement that reward external collaboration could encourage partnerships with regional and extra-regional colleagues (Abramo, D’Angelo, & Murgia, 2013; Acedo et al., 2006; Wagner & Leydesdorff, 2005). At the national and regional level, the forms and sources of research financing can influence the types of collaboration chosen. For example, it could encourage local- and intra-
region-level collaborations, while supra-national financing and in certain cases, the incentive systems to individual organizations, can favor collaborations at the international level (Hoekman et al., 2010). A smart balance must be found between the necessary reinforcement of internal coherence, mainly around the project of collectively “discovering” the relevant specialization, and the challenge of positioning local research in the global world of science. In fact there is no contradiction if the territorial strategy is well defined (Benaim, Herauld, & Mérindol, 2016). In addition, it raises many interesting yet far-reaching questions, such as: which collaborator countries are drivers in fostering and enhancing smart specialization, clusters of innovation, absorptive capacities? Such questions deserve further investigation and suppose future research.

The current study has some limitations. First, scientific capacities of countries are driven by a combination of factors. We consider some of them, such as the income level, expenditures in R&D, and researchers. However, it is necessary to keep analyzing other factors (e.g., scientific capacities, power relationships) affecting international collaborations to better understand conditions and possibilities of the fewer developing countries to access to the global scientific network. Second, as scientific system of science is growing; the scale of bibliographical databases has grown, too, with new journals added in the collection. That means that comparisons over time might differ from current results. Third, in network analysis, the current paper does not consider whether peripheral countries are consolidating positions in the regional and global network. We plan to further study roles of countries (closeness, betweenness, etc.), in the regional and global network. Besides, as the vast differences in volume of production and scientific capacity by country complicate analyses of collaboration, we plan to analyze the temporal evolution of the exchange of knowledge between countries and the relative importance of specific countries in building ties across borders by applying similarity measures (e.g., Affinity Index, Probabilistic Affinity Index (Chinchilla-Rodríguez et al., 2021)) and combining regression analysis with other indicators. The ultimate goal is to help policy-makers in planning research agendas and collaborative alliances.

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References


