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SOCIAL SCIENCES

Funding as a determinant of Citation Impact in Scientific Papers in different countries

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Abstract: Several factors influence the citation impact. This paper constructed paths from funding to citation impact on a country basis. Country data came from Incites® (2011-2020). The (2013 to 2018) UNESCO database was used to define investments in Research and Development (R&D). An overall analysis and analyses by clusters formed by investments in R&D were carried out. Countries that invest relatively less in R&D tend to have less investment by businesses and publish fewer documents. Some differences exist in this pattern. For example, countries in the lowest investment group show higher international collaboration and publications in Open Access Journals. This leads to a higher impact but below countries with the highest investments in R&D. The paths from funding to high impact differed by cluster. While international collaboration appeared in several clusters, the % of papers in Q1 (Top) journal quartile, based on citations, was in almost all clusters. More investments in R&D and open access publishing do not necessarily lead to high impact.

Key words: GERD, Q1 journals, investment, impact, collaboration.

INTRODUCTION

The logistics of having a manuscript accepted are well known (El-Omar 2014, McKercher 2015). Factors affecting citation impact have also been studied, including the effects of publishing open access (OA), collaboration with international and industrial partners, sources of funding (private or governmental), impact factor of the journal, area of knowledge, and language among others. Nevertheless, identifying country variations in the combination of factors that affect citation impact have not studied at length. In this paper, we group countries according to impact factors of their Web of Science publications and then look at the paths from funding sources to citation impact through decisions made by authors such as collaboration type and where to publish and how this affects the end result. We find that differences exist between country groups and therefore funding can be directed to the most efficient solution for that group. These paths can aid in making informed decisions about how and where to publish.

Within each country, funding must be correlated with scientific impact as it influences issues at the frontiers of knowledge. In the USA, Fanelli et al. (2010) found that papers were more likely to support a tested hypothesis if their corresponding authors worked in states that produced more academic papers and had higher R&D expenditure per capita. Therefore, the availability of resources throughout the publishing process is essential. Matters such as the cost of Open Access (OA) publishing (McManus et al. 2020a, Wingfield & Millar 2019) can limit the ability of researchers to attain these goals.

International collaboration (Breugelmans et al. 2018, McManus et al. 2020a) can affect the capacity to pay Article Processing Charges (APCs), increasing open access publishing (Breugelmans et al. 2018, Murphy 2013). These cooperations can then increase the final impact factor of the paper by reaching a wider audience and increasing the number of citations, as high-impact journals tend to have higher citation rates (Miranda & Garcia-Carpintero 2019). Publication citation impact with one or more international or business partners is well-documented (McManus et al. 2020a, McManus & Baeta Neves 2021a). This can be due to increased scientific rigour, with more resources and infrastructure (Hoekman et al. 2010), leading to a more efficient outcome of scientific efforts (Catalá-López et al. 2014). Nevertheless, Breugelmans et al. (2018) found that the international collaboration advantage seems to be region-specific. Patel & Kim (2007) showed that authors from high-income countries are responsible for up to 50% of the research published from low- and middle-income (LAMI) countries. Grácio et al. (2019) showed a benefit in citation impact when the paper has a foreign corresponding author, mainly from a high-income country, compared to an author from a low-income country. The authors state that the proportion of accepted papers from the latter countries in high-impact journals was low. Other factors may influence the result. For example, when looking at Harvard University publications, Gazni & Didegah (2010) found no correlation between international collaboration and citation counts. Didegah & Thelwall (2013) also suggest that the influence of research collaboration on citation impact varies across knowledge areas, primarily institutional and international cooperation. Language and writing style also change in collaboration (Zeng et al. 2011), thus increasing the likelihood of accepting a manuscript.

Other factors such as using text editing services (which must be paid for) before publication and living in a developed, English-speaking country were associated with authors having a greater chance of publishing in a high-impact journal (Paiva et al. 2017). This chance decreased when the researcher used his/her personal resources to perform studies. While public funding is the predominant funding source for university research, its allocation and use vary between institutions and countries (Auranen & Nieminen 2010). Therefore, the availability of resources for new infrastructure, research assistant contracts, postgraduate scholarships or payment of APCs depend on how this funding takes place. According to Confraria et al. (2017), there is no unique path to a country's successful economic development. This paper looks at paths from funding to citation impact as follows: Literature Review, Data and Methodology, Results looking at the overall data set and within clusters formed by resources available for Research & Development (R&D) per capita of the country, Discussion and Conclusions.

LITERATURE REVIEW

As publishing is considered a baseline science and research activity (Blind et al. 2018), in this literature review we look at factors that affect the citation impact of papers, starting with funding and going through factors related to decisions made by the authors (collaboration, where to publish (OA, journal quartile), language, the ramifications of these choices (whether the paper is cited or not) that lead to the number of citations a paper receives and then its impact corrected for the field of knowledge. Here we hypothesise that different countries follow different publishing paths depending on available resources that lead to different impact factors.

Funding for the production and publication of science comes from government (federal, state, local), non-profit foundations, and industry (McManus & Baeta Neves 2021b). When a government shows support for R&D activities, this indicates a guarantee for public benefits (Giebe et al. 2006). Nevertheless, recent budget restrictions may create a need for researchers to acquire funds from other sources (Coccia et al. 2015). Increased research funding can cause a subsequent increase in quality (Quan et al. 2017) and the number of international publications. Pan et al. (2012) state that a country needs to invest more than 100,000 USD per researcher annually for the scientific output to impact higher than the world average.

Using citation impact factors has become common in evaluating scientific research, including individual publications, research groups, research institutions, countries, or journals (Waltman 2016). They are used to infer quality (Moed 2005). Increasing citation impact can be due to several factors, such as international or industry collaboration, publishing open access (OA) in high-impact journals, country wealth (King 2004), or English as a country's official language (Bornmann & Leydesdorff 2013).

Tahamtan et al. (2016) found three general categories (paper, journal and author-related) and twenty-eight factors associated with the number of citations. The size of a nation's scientific community may determine the need for international collaboration (Puuska et al. 2014, Frame and Carpenter 1979). Small countries have been more active in international collaboration, possibly because authors have fewer opportunities to find collaborators inside their own country than authors from larger countries, so they have a greater need for foreign research partners (Narin et al. 1991, Confraria & Godinho 2014). International co-publications in these countries tend to be more wide-spread than those in larger countries (Glänzel 2001). While international collaboration shows positive relationships with citation impact (Jeong et al. 2014), academic excellence is still needed (Fortunato et al. 2018, McManus et al. 2020b). Moreover, these collaborations are affected by several other factors, including relative socioeconomic level, overall scientific activity and geographic distance (i.e., Parreira et al. 2017), which may constrain the impact of citation indices. Oliveira (2016) reinforces this by stating that high-impact publishing requires demanding conditions, interesting scientific/technological problems, trained scientists, infrastructure, and the ability to communicate the results and concepts (Jordan et al. 2003).

Countries that spent more on R&D produced more results (Meo et al. 2013), including the number of publications, citations per document and H-index. Nevertheless, Man et al. (2014) saw that the number of publications correlated with economic conditions only in developing countries but not in more developed countries. Countries with less material and intellectual resources were more likely to look for foreign research partners than richer countries (Luukkonen et al. 1992). Confraria et al. (2017) also found a large gap between higher and lower-income countries. These authors cite actions such as increasing levels of collaboration with highly reputed scientific authors and publishing in high-impact journals to positively affect the citation impact of publications worldwide. Higher international collaboration levels may help countries with both low GDPpc (Gross Domestic Product per capita) and smaller scientific communities. Countries in the scientific periphery (Goldfinch et al. 2003) also benefit from foreign collaboration, while domestic partnerships between institutions in these countries negatively correlate with citation rates (Schubert & Sooryamoorthy 2010). King (2004) and Confraria et al. (2017) found that the relation between GDPpc and citation impact is not strictly positive. Baeta Neves et al. (2020) also found similar results, showing that each citation from a Brazilian author received half the R&D investment (in USD) compared with a citation received by a Portuguese author and 1/12 of that received by an author from Qatar.

The collaborative relationship between businesses and research organisations has been shown to produce competitive advantages and aid in the globalisation of economies and technologies (Iqbal et al. 2011). Businesses that publish more R&D work in quality scholarly publications and maintain more collaborations with academic partners (Jong & Slavova 2014) tend to show higher innovation. Benefits include learning opportunities, enhancing the business's absorptive capabilities, attracting and retaining high-quality scientists. They also indicate possession of strong scientific capabilities to external parties. Most collaborations between corporations and academia are with large international (Confraria et al. 2017, McManus et al. 2021a) R&D-intensive technology companies. These companies tend to be in science-based industrial sectors such as biotechnology & pharmaceuticals, electronics, chemicals, and computers (Godin 1996, Tijssen 2012). Publishing collaborative research with these companies can generate new knowledge and resolve development problems (Perkmann & Walsh 2009).

Gargouri et al. (2010) state that Open Access (OA) indicates a quality advantage (users selecting what to use and cite) rather than a quality bias (authors deciding what to publish as OA). This situation may not be entirely accurate. Björk & Solomon (2015) and Pinfield et al. (2017) showed a correlation between APC (Article Publishing Charges) and citation rates, which may negatively affect researchers unable to pay them. Publishing inequality (James 2017) is notable, as APC charges can exclude publishable papers from those unable to pay. The OA advantage is significant for articles that have met the standards of higher-impact journals (Gargouri et al. 2010) and OA journals show higher citation rates for papers within each journal-impact level. Nevertheless, journal ranking tends to be controversial (Mingers & Harzing 2007), as the individual paper rather than the journal receives the citations (Serenko & Dohan 2011, Nederhof & Visser 2004). Several metrics can measure journal quality, such as SNIP, SJR, and CiteScore (Walters 2017 – see abbreviations in the Glossary). Razumova & Kuznetsov (2019) also noted that, while OA papers show higher citation rates than paywall articles, Green OA (author self-archiving a pre-print or post-print versions of the article) showed higher rates than Gold OA (online, fully accessible, journal articles).

As shown above, several factors affect citation rates, and these can vary depending on the country and institutional factors. The analysis of direct and indirect paths that affect the citation index can help us better understand how to build better funding policies (Bu et al. 2021).

DATA AND METHODOLOGY

Two main data sources were used, Incites© and UNESCO, from which we obtained the country publication and economic data, respectively. Countries were grouped depending on investments made in Research & Development (R&D), and path analyses (based on correlations between indicators) were performed within these clusters to see how different levels of indicators lead to different outcomes (citations).

Publication data on countries, including those from businesses, were collected from Incites® (Clarivate Analytics) for 2011 to 2020 (10 years). The indicators available included the number of Web of Science Documents (WoS), the total number of times cited, number of documents in Top 10% and Top 1% of most-cited journals and their percentages, Percentage of Open Access documents (%OA), % of documents in the directory of Open Access Journals (DOAJ), % of documents per journal quartile (%Q1, %Q2, %Q3, %Q4), % documents in collaboration with industry (%ind), Category Normalised Citation Impact (CNCI - divides the number of citing items by the expected citation rate for documents of the same type, year of publication and subject area), Citation Impact (CI= (), Average Percentile (AVP - mean of percentiles of papers), Impact Relative to the World (IRW=( ), as well as percentages of highly cited (%High - Top one per cent in each of the 22 Essential Science Indicators℠ subject areas per year based on the most recent ten years of publications) and hot papers (%Hot - published in the last two years, receiving citations quickly after publication). See the glossary at the end of the paper for definitions.

Further country data (i.e., spending on research and development) were collected from the UNESCO database (http://uis.unesco.org/apps/visualisations/research-and-development-spending/) and averaged from 2013 to 2018 in USD. The average only included non-zero/non-missing values. These data also included the number of researchers per million inhabitants, GERD (Gross Domestic Expenditure on Research and Development) per capita and GDP (Gross Domestic Product), % government funding (%gov) and % business (%bus) sector funding. These data were collected through an annual survey involving individual countries and regional partners, such as Eurostat, OECD, RICYT (Network for Science and Technology Indicators – Ibero-American and Inter-American) and African Science, Technology and Innovation Indicators (ASTII), and aligned with the recommendations in the Frascati Manual (OECD 2015). Some countries were excluded from the analyses as research funding information (including the percentage from government or business) was not known or CNCI was zero. This included many African and middle eastern countries (see Figure 1), but also Australia (which had no data in the UIS data base) and some South American countries.

Country clusters were formed using Ward's minimum variance method based on country data for resources available for Research & Development (R&D). Number of clusters was chosen using semipartial R^2 and Cubic Clustering Criterion (CCC).

Due to the low number of countries (e.g. cluster 7), some clusters were not evaluated for cluster paths for R&D, and a shortened path was investigated for the other clusters. Path analysis is used to examine the strength of direct and indirect relationships among variables (Streiner 2005, Lleras 2005), disentangling processes underlying a particular outcome. First, an input path diagram, which illustrates the hypothesised relationships between the variables (Figure 2a), was constructed and after the statistical analysis, output path diagrams (Figure 2b and c) were constructed. The hypothesis was constructed from the relationships found in the literature review and taking into account that the variables have a specific time order since one variable cannot be said to cause another unless it precedes it in time.

In the path analysis, the correlation is calculated as the sum of the contribution of all pathways through which the variables are connected (Wright, 1934). Direct paths refer to the direct effect of the variable on CNCI, while

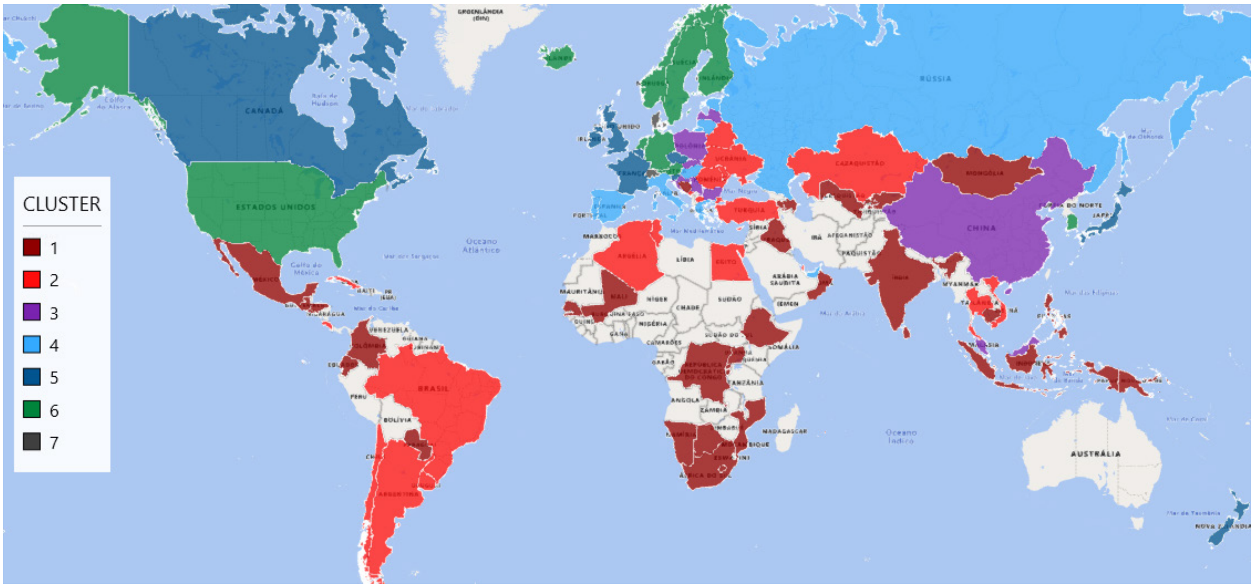

Figure 1. Clusters for countries (103) formed by % of investments in Gross Domestic Expenditure on Research and Development (lowest (1) to highest (7)). Economic data is from UNESCO´s Institue for Statistics (2013-2018). Countries in white do not have available data. Countries are listed in Table SIII.

indirect is when the variable affects another variable, affecting CNCI.

Paths (both direct and indirect) were constructed from funding to impact for the whole country data set and the clusters formed. Two paths were studied, the difference being that in Path 2, Top1% and Top 10% were removed. Paths were chosen based on the null hypothesis that the theoretical path model fits the data, based on the c^2 test. Path coefficients were tested using t tests (Hatcher, 1996).

To reduce the number of variables (from 24 to 17) and to avoid linear dependence between variables, a multiple regression analysis was carried out with CNCI as the dependent variable and all other variables as independent. The variables with a variance inflation factor (VIF) greater than 15 were removed from the path analysis, which led to the removal of AVP, IRW, % Q3, % Q2, % DOAJ, % Hot, and % High. A high VIF means that the independent variable has high co-linearity with the other variables in the model and so can be removed.

After analysing the whole data set, path analyses were carried out within clusters (excluding cluster 7 due to lack of data – only three countries). Multiple Regression Analyses (PROC REG) were carried out within clusters to determine which of the authors' decisions could influence the impact and quality of the papers produced and, thereby, which data to include in the path analyses. Correlations (PROC CORR) described the relationships between the variables studied.

All statistical analyses were performed using routines of SAS®v9.4 (Statistical Analysis System Institute, Cary, North Carolina), including correlation (PROC CORR), multiple regression (PROC REG), cluster (PROC CLUSTER & FASTCLUS) and path analyses (PROC CALIS).

RESULTS

The first analysis looked at the steps from investments to CNCI (Figure 2) without dividing into country groups. Most paths in the analysis were significant, with some of them being noteworthy

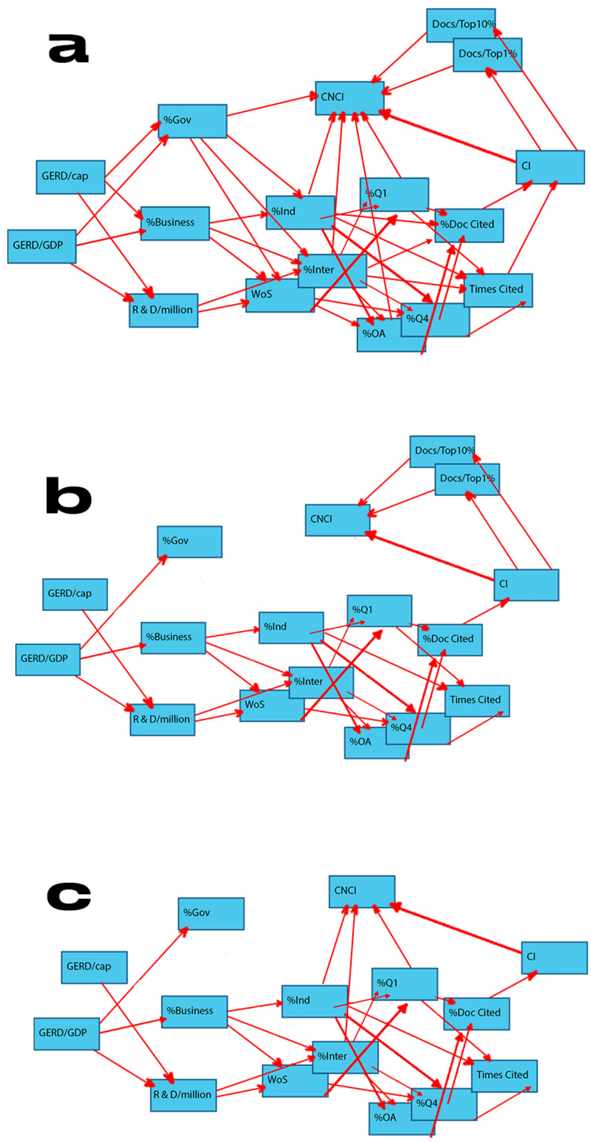

Figure 2. Hypothesised path diagrams (a) from financing (GERD/cap and GERD/GDP) to Category Normalised Citation Impact (CNCI) for all countries; Significant paths (b) Path 1 (path includes percentages of documents in Top 1% and Top 10%) and (c) Path 2 (path excludes percentages of documents in Top 1% and Top 10%). Coefficient estimates for paths are in Table SI, indicating whether the paths are significant and if coefficient effects are positive or negative. Abbreviations are in Glossary. To read the figure, start on the left-hand side (GERD/cap and GERD/GDP). Readers can compare the hypothesised (2a) and significant (2b and 2c) paths. The lack of an arrow means that this path was not significant. Thickness of the arrow line is not relevant. For example, we hypothesised (2a) that GERD/cap would affect the % of government and % business funding in R&D (%gov); this was not significant (no line), but GERD/cap did affect the number of researchers per million inhabitants of a country. The significant paths to the final goal (CNCI) can be followed using the arrows as a guideline.

of attention (Supplementary Material - Table SI). Countries with a higher GERD/GDP showed a lower % of funding by the government (-0.45) and, therefore, a higher % of business funding (0.80). However, more people in these countries were involved in R&D (RD/million) (0.32). Higher RD/million showed a negative effect on the number of papers published (WoS) (-0.42) but a positive effect on % of papers published with industry (0.73) and with international partners (0.74). Higher business funding showed a lower % international collaboration (-0.45). A higher industrial and international collaboration led to a higher % of papers published in open access (0.77 and 0.37, respectively, P<0.001) and in Q1 journals (0.98 and 0.04). This, in turn, led to higher citation rates (0.02 and 1.03). While %Q1 led to a higher % of docs cited (0.42), %OA did not (0.02, P=0.54).

Higher % DocsCited led to a higher Citation Index (0.73) and a higher number of documents in Top1% and Top10% (1.00 and 1.00, respectively). Nevertheless, none affected CNCI (Figure 2b, Path 1). Several variables showed high correlations between them, which may explain the fact that none of the direct effects on a high CNCI was significant in Path 1, but when the % of papers in Top1% and 10% were removed, CI (1.00), %Q1 (0.62) and % International and Industrial Collaboration (0.30 and 0.30, respectively) became significant (Figure 2c, Path 2).

Countries that invest more in R & D also have a higher percentage of business financing. The percentage of funds from the government (Table SII) was negatively correlated with overall funding in research per capita or GDP. This was also negatively correlated with impact indicators such as CI or CNCI. The opposite was seen for the percentage of business funding, except for % international collaborations, showing that international cooperation is mainly financed by the government. A higher budget showed more papers in higher impact indicators (CI and CNCI).

More resources (human and financial) were positively correlated with most other indicators, except % High and % Hot Papers. These, in turn, were positively correlated with % International Collaboration. Funding from business was negatively correlated with % DOAJ.

Clusters of Countries

Seven clusters were formed from R & D data (Figures 1 and 3, Table SIII). Those countries that invest relatively less per capita and GDP in R&D tend to have less investment by business, fewer researchers, and publish fewer documents. Some differences exist in this pattern. For example, those countries in the lowest investment group (Cluster 1) show higher international collaboration and % publication in Open Access Journals. The Path Analysis (Figure 4, Table SIV) for these countries shows that higher international collaboration leads to a higher %OA (0.70) and %Q1 (0.59). A higher %Q1, in turn, leads to a higher % DocsCited (0.44), and this leads to a higher CNCI (0.35), but still below those countries with high R&D investments (Table SV). These countries also show few publications per country with low business involvement in funding. This case highlights the possibility of attracting international collaboration in some countries to increase research impact.

As GERD/GDP increases, RD/million increases and %Gov decreases (Table SIII). Except for Cluster 1, this is accompanied by higher % Business funding, higher % papers published with industry and international partners, and a tendency for higher %OA and higher CNCI.

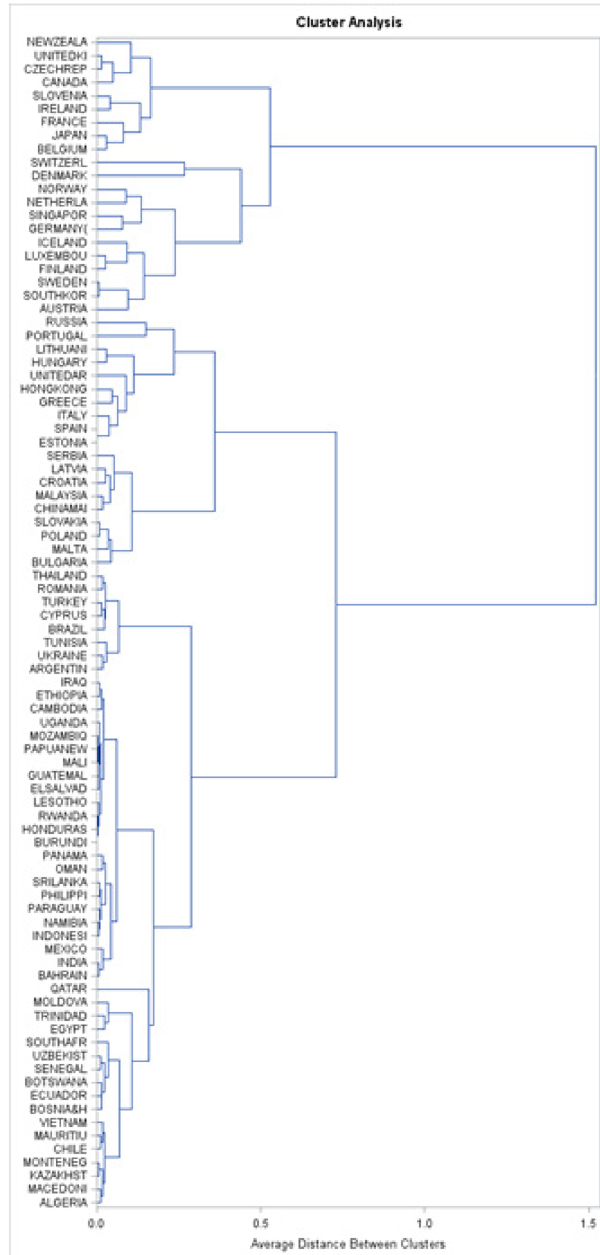

Figure 3. Dendrogram for country clusters formed by financing (GERD/cap and GERD/GDP). Seven clusters were significant. The X-axis indicates the distance between cluster nodes. Countries that join together sooner are more similar than those that join later.

Clusters 1 and 2 showed the lowest investments in R&D (GERD/cap, GERD/GDP and RD/million) but relatively high %Inter (70.99% and 54.35%, respectively), in line with Clusters 6 and 7, but also high %Gov funding (57.72 and 54.58, respectively). Clusters 2 and 3 show the lowest impacts overall, publishing the lowest % in Q1 journals. This may reflect a lack of resources for paying Article Processing Charges (APCs). It may also indicate that government funding in these countries is related to regional or national demands for science or science that is more basic, not in line with international interests and higher citation impacts.

Cluster 7 was not included in the within cluster analysis due to the low number of countries. The paths (direct and indirect) to high-impact publishing differed by cluster, as seen in Table SIV and Figure 4. Some well-established beliefs, such as the direct effect of % OA publishing on CNCI, were only seen in clusters 3 and 4 (0.90 and 0.11, respectively), while its indirect effect on % of Docs Cited was only seen in cluster 3 (-0.55). As seen here, it has a negative impact, possibly due to the publication profiles of countries in this cluster.

More government funding led to fewer publications with industry in clusters 1 and 4. % Inter did not directly affect CNCI in cluster 1, but this cluster had 70% international collaborations, as shown in Table SV. % Gov funding had a direct negative impact on CNCI in clusters 2, 3 and 4 and an indirect effect via % industry collaborations in clusters 1 and 4, as well as a negative effect on % international collaborations in cluster 4 and a positive impact in cluster 6. For cluster 5, there was a negative effect of GERD/capita on % gov funding, positive impacts of % Inter on % OA, and direct effects of %Q1 and % International collaborations on CNCI. Clusters 2, 3 and 4 showed the highest direct impacts on CNCI, including positive effects of %Q1, % international collaborations and % docs cited and a negative impact of % gov funding. % OA did not have a significant effect in Cluster 2. Countries in clusters 1 and 2 should increase % documents in Q1, either through international partnerships or with industry. Clusters 3 and 4 have several options to directly or indirectly improve impact, while 5 and 6 should publish in Q1 journals and increase international collaborations, as coefficient estimations are positive and significant.

As can be seen from the path analyses (Table SIV), there are direct and indirect paths to publishing high-impact papers, depending on the country of origin. The multiple regression analysis highlighted significant ($P<0.05$) variables by cluster (Table SVI) depending on the goal. For example, to attain high CNCI the model included % international collaborations (5 regressions) and publishing in Q1 journals (6 regressions). Higher % Docs Cited is achieved with more GERD/capita in both high and low-impact countries. These differed by clusters, as seen in the path analyses above. The number of papers published generally depended on GERD/cap and GERD/GDP but negatively correlated with RD/million. These were also important for % of docs cited. % Business funding was necessary for impact in higher impact clusters.

DISCUSSION

Scientific research is an essential basis for a strong economy. With reductions in resources available for scientific research worldwide, funding agencies need to examine the most efficient ways to increase the impact of the research they finance. This paper shows that the paths to this impact vary depending on factors including funding source, collaborations, and where and how this research is published. Questions here include how much funding is available for research, the sources of this funding (business, government, international), and where this research is published (Open or Closed Access, international or local journals, etc.). All these factors can affect the citation impact of papers.

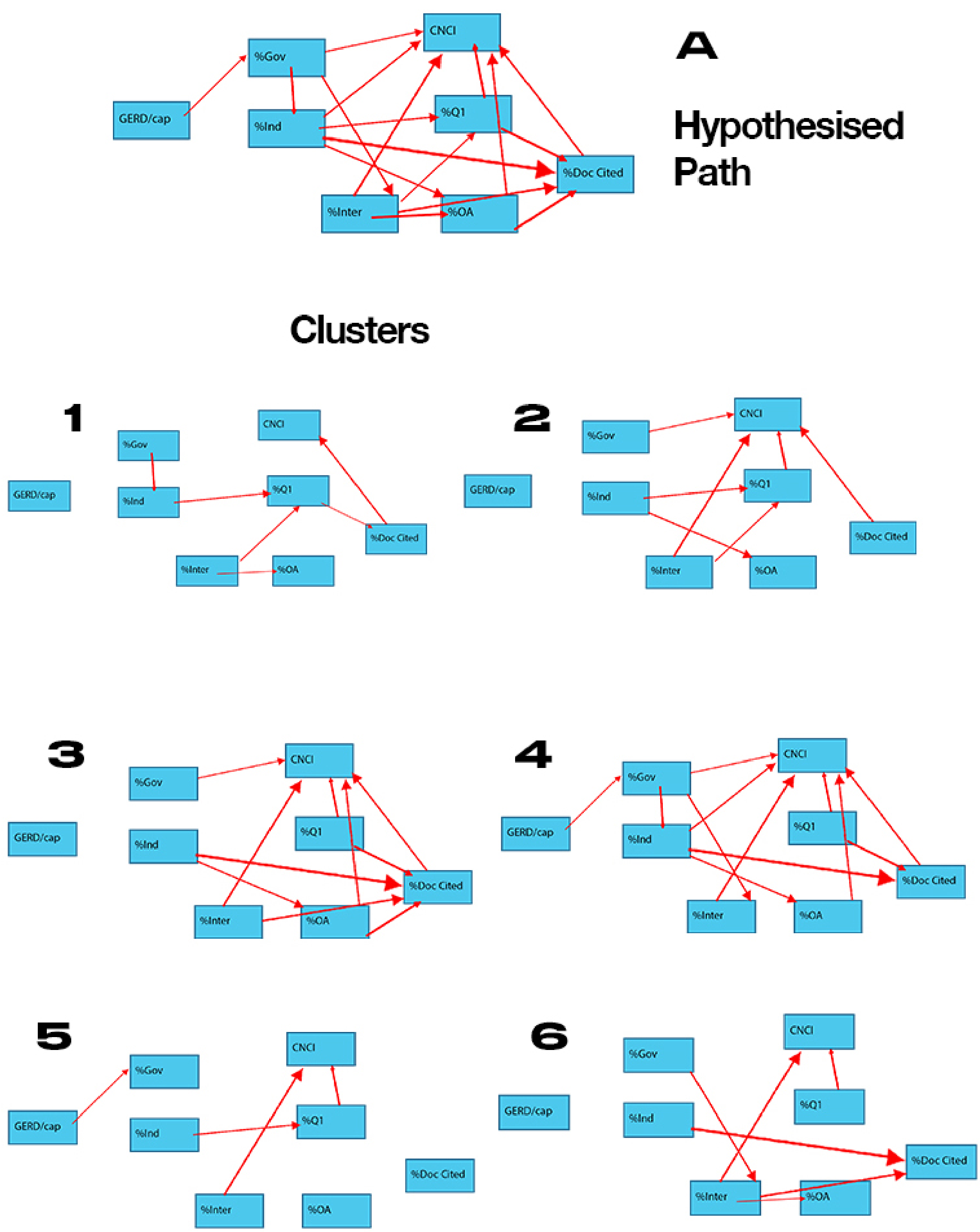

Figure 4. Hypothesised path diagram for within clusters (a) and significant paths by cluster (1 – 6) (See Figure 1 for countries within each cluster and abbreviations are in Glossary).

The government initially finances most research which then can be transferred to industry via patenting, licensing and spin-offs. More recently, university-industry financing and collaboration have increased to include research contracts and consulting (Muscio et al. 2013). Business funding for research usually builds on initial government funding (Sussex et al. 2016). As supported by the analyses shown in the present study, those countries with higher investment in R&D have a higher percentage of research funding on a national scale coming from businesses (Guellec & La Potterie 2004). This facilitates the partnerships between university and industry (Inzelt 2004), experimental development and design, performing trials, and innovation activities within the businesses themselves (Lööf & Heshmati 2005). Businesses using these channels feel the need to create a competitive advantage (Iqbal et al. 2011) by harnessing new technologies. After that, they can use them in their products and processes (Cavalheiro et al. 2016). According to Bruno & Orsenigo (2003), innovative businesses favour research produced by high-quality institutions and published in peer-reviewed journals. Jong & Slavova (2014) show that the disclosure of R&D work in quality scholarly publications and collaborations with academic partners positively affect business innovation.

Bruno & Orsenigo (2003) found that more researchers in a university department attracted more funding from businesses. Businesses or industry funding of research tends to be explicitly related to the enterprise in question (Czarnitzki & Hottenrott 2011), with a large part of private R&D investments spent by large and established companies. Huang & Cheng (2015) also found that larger businesses and those with R&D collaboration commitments with universities have a higher propensity for patenting.

Nevertheless, social returns from basic research tend to be higher than private returns, so most of these activities are financed by the taxpayer. This type of research can be carried out by businesses using their resources (Rosenberg 2009), as they see that basic research contributes to the economy's growth, improving overall welfare.

Glänzel et al. (2014) found that international cooperation is particularly advantageous for less advanced countries, as seen here in Cluster 1. In this cluster, these papers need a high % of articles published in Q1 journals to have high CNCI. This may be achieved with international resources to pay for up-to-date analyses, access to information, translation of papers or APCs, for example. The overall system (global and national) may become more productive and efficient, but at the expense of national visibility and local connectivity. Mêgnigbêto (2013) showed that West African countries tended to cooperate less and less with African and developing countries than developed ones. Tijssen (2007) reported international cooperation between African countries ranging from 29 to 87 %.

According to Chinchilla-Rodríguez et al. (2018), scientific relationships are highly resource-dependent. These authors show that countries such as those in clusters 5, 6 and 7 in our analyses have high foreign collaboration but low mobility, while BRICS countries have lower mobility and collaboration (India and South Africa in Cluster 1, Brazil in Cluster 2, China in Cluster 3 and Russia in Cluster 4). They highlight linguistic, historical, political and cultural linkages in creating networks, with more-advanced countries being central to the networks (see also Parreira et al. 2017). Nevertheless, countries such as India and South Africa (both seen in Cluster 1) have engaged in policies and practices encouraging international partnerships, leading to increased CNCI (Path %Inter to %Q1 to % DocsCited to CNCI). Therefore, international collaboration and mobility are important (Jacob & Meek 2013) for the construction of public funding policies.

Iyandemye & Thomas (2019) state that collaborative research promotes OA, but collaboration alone cannot explain the high percentage of OA publication observed in the low-income group or the low rates in the middle-income groups, as seen here. These authors found that Sub-Saharan Africa has a low number of OA policies but the highest percentage of OA publication of any region (as seen in Cluster 1, Table SIV). On the other hand, South Asia and the Middle East & North Africa, the two areas with the fewest OA policies, have the least OA publications. This suggests a complex and non-linear relationship between OA policy and OA publication, as seen in our cluster analysis.

Article citations generally correlate with article importance (Iyandemye & Thomas 2019), which in turn may be strongly related to the overall quality of scientific research and how financing allows researchers to be at the frontier of scientific knowledge in their fields (Meo et al. 2013, Oliveira 2016). Several important paths in our analyses can be interpreted in this context. Even so, the impact of OA itself can be measured by the number of citations of OA articles compared to those of similar non-OA articles. Citation advantages are shown for OA publications (Schöpfel 2017). Nevertheless, according to Wingfield & Millar (2019) and McManus & Baeta Neves (2021a), open access negatively affects academics in poorer countries, as this model only changes who pays. Rather than institutions paying to have access to publications, researchers are increasingly expected to pay APCs to publish their research in OA journals, which is not sustainable in some lower-income countries. Therefore, collaborating with richer countries can help alleviate this burden, so OA publication resulting from international collaborations is another benefit of collaborative research, as seen in Cluster 1.

The question of national sovereignty relates to the fact that science is also essential in constructing national identities (Harrison & Johnson 2009). The heterogeneous context of developing research and collaborating within each country can limit international collaboration (Jacob & Meek 2013). Vessuri et al. (2013) show a need for policies that focus on improving science in developing countries but maintain the possibility of solving regional or local problems. On the other hand, various authors (Meneghini & Packer 2007, Aguado-Lopez et al. 2012) have attributed the increased impact and visibility of Latin American and Caribbean (LA-C) research to the development of regional information systems such as SciELO and REDALyC (major countries such as Brazil, Argentina and Chile are in Cluster 2, which, together with Cluster 3, has the lowest CNCI). SciELO journals, for example, tend to be Open Access but not necessarily high impact as measured by Incites® and Scival®. This may explain the divergent results for OA journals in different clusters, whereby Open Access does not necessarily lead to high impact.

Publication in Q1 journals gives more consistent results, with most clusters showing a direct path from %Q1 to CNCI and indirect paths. Nevertheless, Tayyab & Boyce (2013) comment that, in some fields, Q1 journals may have a low impact, with the journal impact factor increasing with the number of journals. Researchers may thereby opt to publish their research in low Impact Factor Q1 journals. Vessuri et al. (2014) show that scientific competition depends on where researchers publish and journal reputation. Therefore, science policy requires looking at scientific journals' production, circulation and consumption, especially in "peripheral" countries. Citations may not be related to the use of science for development, as most of the more important and highly cited journals in international databases come from OECD countries and operate under their rules (Guédon 2011).

Regional collaboration may be important for developing countries to improve their national scientific infrastructure (Woolley et al. 2017), especially for those who do not have access to the more elite scientific networks. For example, regional social and political variables can explain the increase in scientific papers of some LA–C countries in both local and international indexed journals (Moya-Anegon & Herrero-Solana 1999). Another question not discussed here is whether the indicators used here can attribute excellence (Guédon 2011). Collazo-Reyes (2014) and Hollanders & Soete (2011) showed that, although increasing, LA-C countries show low representation in international databases, preferring to publish in national journals, with low impact (Luna-Morales & Collazo-Reyes 2007). This may be because of the low R&D investments in these countries, the inability to pay APCs, the lack of text editing services, or research concentration on local or regional interest themes. McManus et al. (2020a) estimated USD 3,959,260 was for translation costs (calculated for 10% of the papers except when the journal demands a translation certificate when 90% was used), USD639,887.50 for submission costs and USD32,417,620 for Article Processing Charges (APC) in the Top 50 journals where Brazilian authors publish over a ten-year period.

Funding agencies should consider results here when creating policies, especially when resources are scarce (McManus et al. 2021a). Funding differs when it looks to improve impact for the country as a whole rather than for a select group (Vessuri et al. 2014). These authors pointed out that publishing in international journals may benefit research areas preferred by more developed countries. As seen from the path analyses shown here, there are direct and indirect paths to publishing high-impact papers, depending on the country of origin. While international collaboration, open access publishing, and Q1 journals are strong indicators of paper impact, this was not true for all clusters. Vinkler (2018) also saw that country development (measured as GDPpc) could strongly influence but not determine the structure of science in different areas of knowledge. Analyses within knowledge areas may therefore be warranted. Indeed, Gonzalez-Brambila et al. (2016) saw significant heterogeneity between countries regarding their R&D infrastructure, fields of knowledge, language and publication profiles, so comparisons may be unfair. Thus, clustering countries and examining differences between these using other qualitative and qualitative measures could help in understanding different publishing behaviours.

CONCLUSIONS

Publishing high-impact papers depends on various factors, depending on the country of origin. The direct and indirect paths from funding to impact publishing differed by the cluster of nations. Thus, higher investments in Research & Development and publishing in Open Access journals do not necessarily lead to high-impact publishing. Nevertheless, countries with low investments can choose alternative paths, including higher international collaboration or publication in Q1 journals that lead to higher impact and recognition of the research in the country.

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SUPPLEMENTARY MATERIAL

Tables SI-SVI.

How to cite

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GLOSSARY

AVP - Average Percentile - mean of percentiles of papers. The percentile of a publication is determined by creating a citation frequency distribution for all the publications in the same year, subject category and of the same document type. The percentage of papers cited more often than the paper of interest. If a paper has a percentile value of one, then 99 per cent of the papers in the same subject category, year, and document type have a lower citation count. For any set of papers, an Average Percentile is calculated as the percentile mean of all documents in the collection.

CI - Citation Impact = ()

CiteScore - the number of citations received by a journal in one year to documents published in the three previous years, divided by the number of documents indexed in Scopus published in those same three years

DOAJ - Directory of Open Access Journals is a community-curated online directory that indexes and provides access to high-quality, open access, peer-reviewed journals.

DocCit – Number of documents in the database in the period studied that had at least one citation in the database

FWCI – Field Weighted Citation Index - is the ratio of the total citations received by the denominator's output and the total citations expected based on the average of the subject field. Similar to CNCI, this is from SciVal® based on data from Scopus.

High – Highly cited papers are papers that perform in the top 1% based on the number of citations received compared to other papers published in the same field in the same year, based on the most recent ten years of publications. Not identical to % Documents in the Top 1% in Incites.

Hot – Hot papers - papers published in the last two years that receive citations quickly after publication. These papers have been cited enough times in the most recent bi-monthly period to place them in the top 0.1% compared to papers in the same field and added to the database in the same period.

CNCI - Category Normalised Citation Impact – divides the number of citing items by the expected citation rate for documents of the same type, year of publication and subject area. The CNCI of a set of documents, e.g. the collected works of an individual, institution or country/region, is the average of the CNCI values for all the documents in the set. This is used in InCites® and based on the Web of Science.

GDP - Gross Domestic Product - the total market value of all final goods and services produced within a country in a given period.

GERD - Gross Domestic Expenditure on Research and Development - the total expenditure (current and capital) on R&D carried out by all resident companies, research institutes, university and government laboratories, etc., in a country. It includes R&D from abroad but excludes domestic funds for R&D outside the domestic economy.

Industry Collaboration - An industry collaborative publication lists its organisation type as “corporate” for one or more of the co-author’s affiliations.

International Collaboration - Papers that contain one or more international co-authors.

IRW - Impact Relative to the World =( ) - Citation impact of the set of publications as a ratio to the world average. This indicator does normalise for the year but does not consider the differences in the subject mix that an institution or a country/region is publishing in.

R&D/million - number of researchers per million inhabitants of a country.

Times Cited - number of times the set of papers were cited.

WoS - Number of Web of Science Documents.

JCR - Journal Citation Reports (JCR) is a resource tool published annually by Thomson Reuters (formerly ISI) to provide citation and publication data of academic journals in the science and Social Science fields.

JIF – Journal impact factor – A tool for evaluating and comparing journals. The average number of times articles from the journal published in the past two years have been cited in the JCR year.

JNCI - The Journal Normalized Citation Impact indicator is a similar indicator to the Normalized Citation Impact. Instead of normalising per subject area or field, it normalises the citation rate for the journal in which the document is publishing.

OA - Open Access - is a set of principles and a range of practices through which research outputs are distributed online, free of cost to the reader or other access barrier

Publications in **Top Journal Percentiles** indicate the extent to which an entity›s outputs are present in the most-cited journals in a database source. This metric calculates how many publications, as an absolute count or a percentage, are in the top 1%, 5%, 10% or 25% of the most-cited journals indexed by the database source. An entity can be an institution, a research group or an individual researcher. In this paper, we used %Top1% and %Top10%.

Q1, Q2, Q3, Q4 - Quartile rankings are therefore derived for each journal in each of its subject categories according to which quartile of the IF distribution the journal occupies for that subject category. Q1 denotes the top 25% of the IF distribution, Q2 for the middle-high position (between top 50% and top 25%), Q3 middle-low position (top 75% to top 50%), and Q4 the lowest position (bottom 25% of the IF distribution). In this paper, we used %Q1 and %Q2.

Scopus - is Elsevier’s abstract and citation database launched in 2004 and covers three sources: book series, journals, and trade journals. All journals covered in the Scopus database, regardless of who they are published under, are reviewed each year. Searches in Scopus also incorporate searches of patent databases

SNIP – Source Normalised Impact per Paper: accounts for field-specific differences in citation practices. It does so by comparing each journal’s citations per publication with the citation potential of its field, defined as the set of publications citing that journal

SJR – Scientific Journal rankings - is a measure of the scientific influence of scholarly journals that accounts for both the number of citations received by a journal and the importance or prestige of the journals where the citations come from

WoS – Web of Science is a website that provides subscription-based access to multiple databases that provide comprehensive citation data for many different academic disciplines. It was initially owned by the Institute for Scientific Information (ISI) and is currently maintained by Clarivate Analytics (previously the Intellectual Property and Science business of Thomson Reuters

Percentages

% DOAJ (Directory of Open Access Journals) - is a website that hosts a community-curated list of open access journals maintained by Infrastructure Services for Open Access.

% of documents per journal quartile (%Q1, %Q2, %Q3, %Q4), Number of documents that appear in a journal in a particular Journal Impact Factor Quartile in a given year. For instance, if a value of 100 is displayed, it indicates that 100 documents in the set were published in journals of the specified Journal Impact Factor Quartile that year.

% of documents with industry (%ind) or international (%inter) collaborations - the number of International or Industry Collaborations for an entity (as described above) divided by the total number of documents for the same entity represented as a percentage.

% of total financing for R&D coming from business (%bus).

% of total financing for Research & Development (R&D) that came from the government (%gov).

%**High** - top one per cent in each of the 22 Essential Science Indicators[SM] subject areas per year based on the most recent ten years of publications - number of ESI Highly Cited Papers for an entity (paper, author, institution, country, journal and field) divided by the total number of documents produced by the given entity, represented as a percentage.

%Hot –Percentage of publications assigned as Hot Papers in ESI (top 0.1% by citations for field and age - papers published in the last two years, receiving citations quickly after publication).

Documents in Top 10 (%Top10%) and 1% (%Top1%) - most cited documents (as defined in the description of Average Percentile) in a given subject category, year and publication type divided by the total number of documents in a given set of documents, displayed as a percentage.

Open Access (%OA) - set of principles and practices through which research outputs are distributed online, free of access charges or other barriers.

% ind - papers published with Industry Collaboration

% inter – papers published with International Collaboration

Statistics

Cluster analysis – organising items into groups, or clusters, based on how closely associated they are. Objects in the same group are more similar to each other than to those in other groups.

Multiple regression analyses the relationship between a single dependent and several independent variables. The objective of multiple regression analysis is to use the independent variables whose values are known to predict the value of the single dependent value.

Stepwise regression is the step-by-step iterative construction of a regression model that involves selecting independent variables to be used in a final model. Potential explanatory variables are added or removed in succession and tested for statistical significance after each iteration.

Correlation - any statistical relationship between two random variables or bivariate data, whether causal or not. Varies from -1 to 1.

Path analysis - a subset of structural equation modelling, used to discern and assess the effects of a set of variables acting on a specified outcome via multiple causal pathways. It can compare different models to determine which one best fits the data. There are two main requirements for path analysis. All causal relationships between variables must go in one direction only (you cannot have a pair of variables that cause each other). The variables must have a specific time order since one variable cannot be said to cause another unless it precedes it in time.

VIF - variance inflation factor - a measure of the amount of multicollinearity in a set of multiple regression variables. It is the variance ratio of estimating some parameter in a model that includes numerous other terms (parameters) by the variance of a model constructed using only one term. It provides an index that measures how much the variance of an estimated regression coefficient is increased because of collinearity.