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International collaboration clusters in Africa

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Abstract Recent discussion about the increase in international research collaboration suggests a comprehensive global network centred around a group of core countries and driven by generic socio-economic factors where the global system influences all national and institutional outcomes. In counterpoint, we demonstrate that the collaboration pattern for countries in Africa is far from universal. Instead, it exhibits layers of internal clusters and external links that are explained not by monotypic global influences but by regional geography and, perhaps even more strongly, by history, culture and language. Analysis of these bottom-up, subjective, human factors is required in order to provide the fuller explanation useful for policy and management purposes.

Keywords Collaboration · Visualisation · Policy · Africa · Regional factors · Cultural factors

Introduction

Georghiou (1998) drew attention to the phenomenon of increasing co-authorship in research publications and, noting previous studies including Frame and Carpenter (1979), associated this particularly with major global research facilities and cooperative programmes. He

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identified a number of barriers to the potential growth of 'bottom up' cooperation but concluded that formal 'top down' enabling arrangements were emerging through, for example, the European Framework Programmes (FPs). Persson et al. (2004) noted deepening scientific collaboration and increasing citation impact in all science areas. In particular, authorship was increasing exponentially while the number of collaborative papers was increasing linearly so connectedness was intensifying. Greene (2007) confirmed this trend and King (2012) described the growing frequency of massively multi-authored papers.

Wagner and Leydesdorff (2005) argued that patterns in international collaboration in science can be considered as network effects and that only the European FPs noted by Georghiou (op. cit.) mediated relationships at that level. Their global network shares features with other complex adaptive systems in which order emerges from interactions between many agents pursuing self-interested strategies. Adams et al. (2007) pointed to the intense levels of interactions between leading research economies. Leydesdorff and Wagner (2008) suggested that the global network reinforced a core group of (14) cooperative countries with strong national systems. They argued that peripheral countries could be disadvantaged by increased strength at the core.

Wagner (2008) argues, from complex systems theory, that the self-organizing global system influences all lower systems. Here, we accept the meta-pattern but contest the network as a sufficient explanatory model and concur with Georghiou, that there are other agents such as major facilities (e.g. CERN—see King 2012) and cooperative programmes (e.g. WHO, FAO, climate change) which have been important. In addition, we argue that the effects of history, culture and language continue to have a profound human influence on collaboration patterns, mediated through personal preference rather than strategic logic (Adams 2012, 2013). The consequence of this is that global collaboration is not a self-same system. It is not self-organizing at the general level because it does not explain local outcomes and is not explained by the integration of local or regional factors.

In this paper we illustrate these effects through an analysis of collaboration patterns in Africa (see also Adams et al. 2010). Africa contains more than 50 nations, hundreds of languages, and a welter of ethnic and cultural diversity. OECD's African Economic Outlook (OECD et al. 2011) sets out in stark detail the challenge for the research base in Africa and the extent to which current global economic problems may make this worse and further compromise the value of the commitment made in by developed nations 2005 to double official development assistance to Africa by 2010. More than half the African nations are off-track or regressing on objectives to achieve universal primary education by 2015. Internet penetration is good only in North Africa, constraining communication and access to knowledge. It needs international research partners.

The level of collaboration in Africa has been noted previously to be relatively low (Bishoff 2010) and often outweighed by collaboration with non-African states (Onyanche 2011). Is the uniform, generic pattern perceived elsewhere nonetheless found in Africa, or does the continent exhibit more subtle influences in its patterns of research collaboration such as those that Onyanche (op. cit.) suggests are regional? and, picking up the visualisation methods compared by Leydesdorff et al. (2013), how can we best represent what we see?

Methods

We focussed on research publications with one or more addresses for a country within Africa as defined by the UN. We sampled data for the period 2000–2012 (data to current indexing, not year-end).

We collated data on gross domestic product (GDP) for each country for which publication data were available. Absolute volume of published papers is one indicator of research activity and—indirectly—of research capacity. The output of a country reflects how much money is going into its research system (gross expenditure on R&D, GERD), and that is likely to be partly dependent on its general economy GDP. Bigger countries with a larger economy should if they invest at the same level as smaller countries, produce more papers,. However, land area, population density and resources also vary a great deal. We compared publications with GDP for each country, reasoning that proportionate investment in the knowledge economy is a good index of a government's commitment to maximize the longer term benefit of resource development and exploitation for the general wealth of its people.

Publication volume and subject analyses used Thomson Reuters *National Science Indicators*. Collaboration analyses were carried out using *Research Performance Profiles* data in *InCites*^{TM}, a web-based platform for research evaluation from Thomson Reuters. Database years were used to delineate years, and only article, note and review document types were considered.

We counted all collaborations between countries represented by co-authorship on the publications we collated. The counts are by paper not by number of researchers. For example, a paper co-authored by two researchers from Ghana, three from Nigeria and one from Kenya counts as a single paper in each country's total and as one link between each pair of countries.

Analysis was extended using Wolfram Mathematica® 7 using CommunityStructure-Partition, (part of the graph utilities package) to create maps and collaboration diagrams, following Clauset (2005). There are a large number of algorithms that will reasonably lead to a decomposition of a graph into communities. The key concept in doing this is "Community Modularity". A graph (composed of a set of edges and a set of nodes) can be broken down into sub-collections of nodes or edges in such a way that each subset belongs only to one community. The limit of this is that each node is a member of a separate community. The algorithm in the reference above starts by assigning each node to its own community, then calculating the change in the overall modularity for the graph if that node happened to be added to another node for the sake of the community decomposition. It will merge the two nodes that give the highest positive change in the modularity. The process is repeated until a higher modularity cannot be reached. Hence, this is really an optimisation problem in which the modularity needs to be maximised. We also had access to the data collected about 2011-publications by Leydesdorff et al. (2013), and extracted the subset of African countries.

Results

Total research output for Africa increased from 13,271 publications indexed on Thomson Reuters Web of Science in 2000 to over 35,000 publications in 2012 (34,528 catalogued at Dec 15, 2012). For reference purposes, the total output of Africa is about the same as that of the Netherlands.

The percentage of Africa's publications that were substantive research papers (that is to say, articles or reviews) declined from 88 to 82.6 %, which reflects an increasing number of proceedings papers and other contributions authored within Africa (Fig. 1).

The number of articles and reviews that have been authored wholly within Africa (i.e. that have no collaborative co-author from outside the region) has doubled since 2000 from

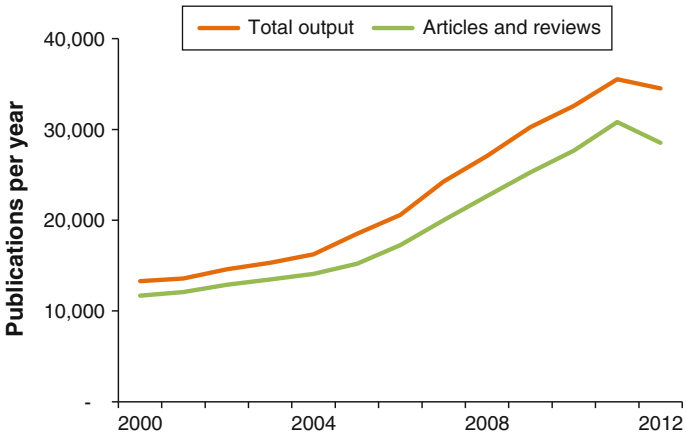

Fig. 1 Africa's output of publications indexed on Thomson Reuters *Web of Science* databases between 2000 and 2012

6,319 to 12,089. This is a decline as a percentage of total research paper output from 54 to 42 %. However, the relative collaborative output of G8 countries rose much faster over the period: collaboration is increasing everywhere. Thus, in fact, the autonomous research output of Africa clearly grew in the last decade and Africa is becoming increasingly self-reliant in this regard.

A breakdown of the figures demonstrates the extent to which each region—and African science as a whole—is dominated by three nations: Egypt in the north, Nigeria in the middle, and South Africa in the south. In this millennium, since 2000, Egypt produced nearly 58,000 publications which was more than twice the total for Tunisia, its next-place and regional neighbour. In west-central Africa, Nigeria's total for the same period was over 20,000, compared to roughly 12,800 for Kenya which is the leading research economy in the east of the continent. South Africa's dominance, as might be expected, is even more pronounced: over 95,000 publications since 2000, compared to the southern region's next-most-prolific nation, Tanzania, which fielded just over 6,300 (Table 1).

What happens when we break the publication data down by field of research? in our recent Global Research Report on Africa we showed a discernible pattern in Africa's relatively high representation—as a share of world publications—in fields that are relevant to natural resources. The highest percentage of any field, for example, is South Africa's 1.55 % share of Plant and Animal Science. Not far behind is the same country's 1.29 % share of Environment/Ecology. A review of the more detailed analyses in Thomson Reuters *Essential Science Indicators* shows that many of South Africa's most highly cited papers in this field pertain to climate change and its effects on plant propagation. Following this theme, South Africa's 1.13 % share of Geosciences is in keeping with the region's mineral richness.

In short, Africa is a continent abundant in natural resources. How much does Africa itself benefit from those resources? the leading countries by output are South Africa, Egypt, Nigeria, Tunisia, Algeria and Kenya. Four of these (South Africa, Egypt, Nigeria and Algeria) are also leading countries in terms of GDP while Kenya and Tunisia fall in a lower GDP tier. Indexing output against GDP provides further interpretation. Zimbabwe is highlighted as relatively the most productive country in terms of publications per unit GDP but this is anomalous because it retains its legacy research base despite a collapsing

Table 1 Research output and collaboration (all publications on *Web of Science*, 2000–2012) between the USA, UK, France, Saudi Arabia and their most frequent partners in Africa

Africa—total	296,351	USA 39,292	France 31,421	UK 25,753	Saudi Arabia 6,285
South Africa	95,309	14,264	3,801	10,131	
Egypt	57,741	5,900	1,019	2,409	4,939
Kenya	12,769	4,260	460	2,791	18
Uganda	6,317	2,318	231	1,402	11
Nigeria	21,909	1,945	243	1,426	54
Tanzania	6,299	1,693	171	1,625	8
Ghana	4,945	1,159	156	1,003	14
Malawi	2,909	990	124	1,087	
Morocco	17,518	956	5,738	559	186
Ethiopia	5,579	933	218	576	26
Cameroon	5,915	832	1,730	548	
Tunisia	24,724	755	7,400	421	326
Senegal	3,634	573	1,622	275	3
Algeria	14,846	412	5,961	292	367
Gambia	1,294	297	86	857	
Gabon	1,188	241	504	205	

economy and very low current GDP. The real leaders are Tunisia and Malawi with very different economic bases but strong relative productivity in both cases. South Africa, Kenya and Egypt all have significant relative productivity, as do a number of other countries in East Africa (Ethiopia, Uganda, Tanzania) and West Africa. (Cameroon, Ghana).

Africa's research can be boosted by collaborative international partnerships as noted by Onyanche (2011). The countries collaborating most frequently with partners in Africa are the USA (39,292 papers between 2000 and 2012), France (31,421), the UK (25,753), Germany (13,879) and Canada (7,604). This looks like a roll-call of 'the usual suspects' among major research producers and this element would therefore accord with the generic global model. It is therefore worth noting that Saudi Arabia collaborated on 6,285 papers, albeit almost entirely with countries in North Africa of which Egypt (4,939 joint publications) was the pivotal link. By contrast, Ethiopia's research base is distinctive in being substantial, growing and yet almost entirely domestic. The most substantial links between countries in Africa and the USA, UK, France, Saudi Arabia are summarised in Table 1.

The research axis between Egypt, Saudi Arabia and the USA is an instructive example of new and changing collaboration patterns. The numbers of papers co-authored between Egypt and the USA has grown but has remained around 10 % of Egyptian output since 1995. The numbers of papers co-authored between Egypt and Saudi Arabia has been much smaller historically but reached 100 (4 % of Egypt's output) in 2002 and exceeded 1,000 (15 %) in 2011. This is regionally, not globally, driven: only a small fraction of these papers also have the USA as a co-author (Table 2).

France also has a niche relationship with Africa. It is unusual in studies of international collaboration to find it high in any ranking, and here to be 2nd behind the USA, ahead of the UK and with much more than twice the collaboration links of Germany. Among the 31,421 total co-authorships by partner then we find that Tunisia (Table 1: 7,400 23.6 %)

Table 2 Growth of Egypt's research output and its collaboration with the USA and with Saudi Arabia over thirty years from 2000 to 2012 (part year)

Years	Egypt total	Egypt + USA	USA as % Egypt	Triple co-authors	Saudi as % Egypt	Egypt + Saudi
2000	2,577	286	11	2	4	95
2001	2,707	227	8	3	3	94
2002	2,894	295	10		4	115
2003	3,238	312	10	7	6	181
2004	3,212	318	10	4	5	169
2005	3,338	326	10	3	5	164
2006	3,847	358	9	6	5	190
2007	4,280	424	10	8	5	199
2008	4,710	439	9	15	6	261
2009	5,725	597	10	20	7	416
2010	6,281	708	11	33	10	614
2011	7,416	823	11	55	15	1,093
2012 (part)	4,386	428	10	47	19	832

Egypt has increased collaboration with Saudi Arabia and little of this is driven by its prior links with the USA

leads with Algeria (19 %), Morocco (18.3 %) and then Cameroon (5.5 %). France is focussed on a small set of countries just across the Mediterranean in North Africa. The USA and the UK provide a further contrast and collaborate diversely with South Africa, Kenya, Egypt, Nigeria and others (Table 1). The UK has much greater collaboration with specific countries, such as the Gambia and Malawi, than any other partner.

No collaboration pattern in Africa is general or uniform. For each of six key research economies in Africa we have analyzed collaborative research links by collating co-authorships with other countries and analyzing collaboration with the USA and the UK as the most frequent partner for most countries, and three other frequent partners (Figure 2).

How can we best visualise research co-publication within Africa? first, to create a simplified picture useful as an indication of major links for policy purposes, we used a threshold to clarify where relatively strong and persistent collaborations occurred. The threshold was set at a minimum of five papers per year, or 25 papers in total over the recent five-year period. This meant that some countries did not appear at all in the analysis because they had too low a level of recent collaboration. We then used a grouping algorithm to associate the countries around the rim of the wheel until groups with strongest cross-links were placed close together (Fig. 3).

Second, we created a more complete but necessarily more complex picture of the entire Africa network 2011 using VOSViewer (Fig. 4).

Discussion

This analysis presents a complex picture of diverse research collaboration links, internationally (Table 1; Fig. 2) and within Africa (Figs. 3, 4). It is difficult to argue that these outcomes are a response to a common global network phenomenon rather than local, cultural and historical factors that play into research opportunities (Georghiou 1998) and

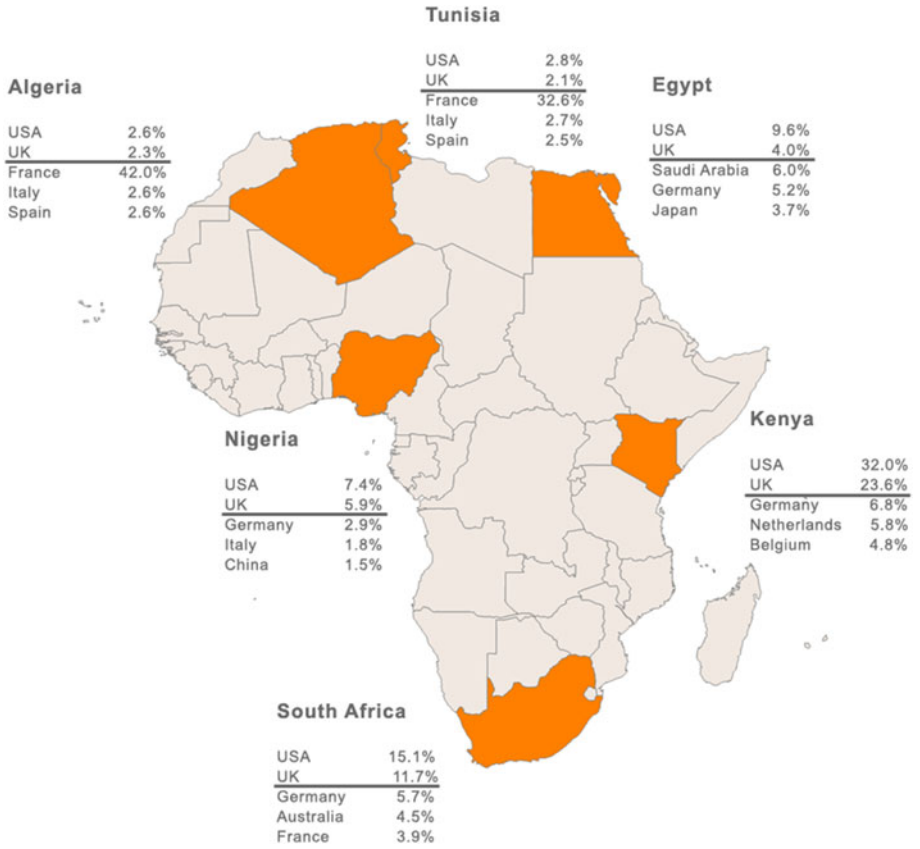

Fig. 2 Most frequent intercontinental research collaborations for six key African research economies

create the highly individualistic and specific African outcome. We do not disagree with Wagner's (2008), Wagner and Leydesdorff (2005) concept of international research collaboration as a common phenomenon but we do not see the self-organizing network in these data. Rather, we see a continuing need to examine the bottom-up factors that explain complex regional and local outcomes departing from the top-down global template.

Onyanche (2011) argued that collaboration within Africa was markedly regional whereas Bishoff (2010) commented on the stronger cross-regional links between South Africa and Kenya and Nigeria rather with other The Southern African Development Community (SADC) countries. In fact, South Africa is the pivot of a regional hub while Nigeria is linked not to its geographic West Africa region but to co-anglophone East Africa. The picture is thus extremely complex and depends on perspective as much as data.

The research output of Africa is small compared to established economies but it is growing (Fig. 1). Africa has enormous natural resources yet, while there is a broad relationship with investment as GDP, some richer countries have yet to commit to substantial investment in their knowledge economy. This contrasts with the more general global pattern.

External collaborative links vary by country. France is the second most frequent collaborator with Africa, after the USA, with concentrated links to North-West Africa and to

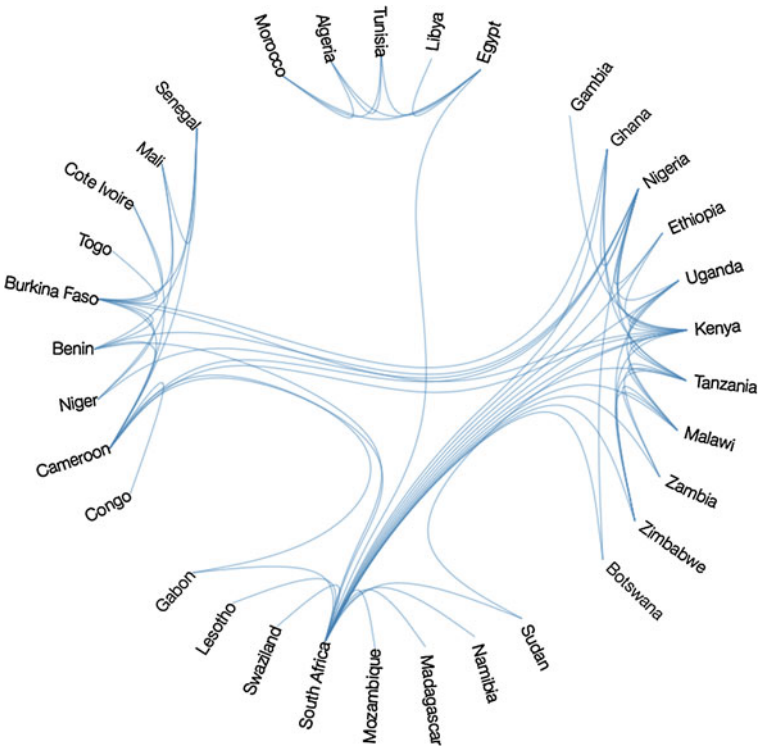

Fig. 3 Collaboration between countries within Africa. This dependency graph uses *Wolfram Mathematica*® *7 to* provide a new visual interpretation of collaboration, by paper not by number of researchers, and reveals clusters of countries with strong and persistent partnerships. Links displayed between each country meet a threshold of five publications per year for a continuous period of 5 years

central West Africa. It is interesting to note that, after normalization for size, Leydesdorff and Wagner (2008: 321) found France as highest on betweenness centrality because of its intermediating function with the EU networks. The UK is the most frequent collaborator with other African countries, such as Malawi and Gambia (Table 1). These links are not driven by global phenomena but by local historical and cultural factors and by targeted international cooperative health and food programmes. Many links are mediated through cooperative health and agricultural programs. Gambia is the site for long-term research into tropical diseases for the UK's Medical Research Council (Adams et al. 2012) which also works in Uganda. The Wellcome Foundation has similar, major research investments in Kenya and Malawi. A significant intellectual benefit is thus secured outside Africa.

Another exceptionally strong link is that between Egypt and Saudi Arabia, which is not mediated by a third party such as the USA (Table 2) but through their axis in supporting regional growth in research capacity in the Arabian Middle East (Fig. 2; Adams et al. 2011).

How can we create a picture of Africa's research network that would be helpful for policy engagement? if we apply a threshold on the strength of interaction we find no single network within Africa. Interface with African countries requires awareness that collaboration is driven partly by geography but also by shared culture and—very strongly—by language (Fig. 3).

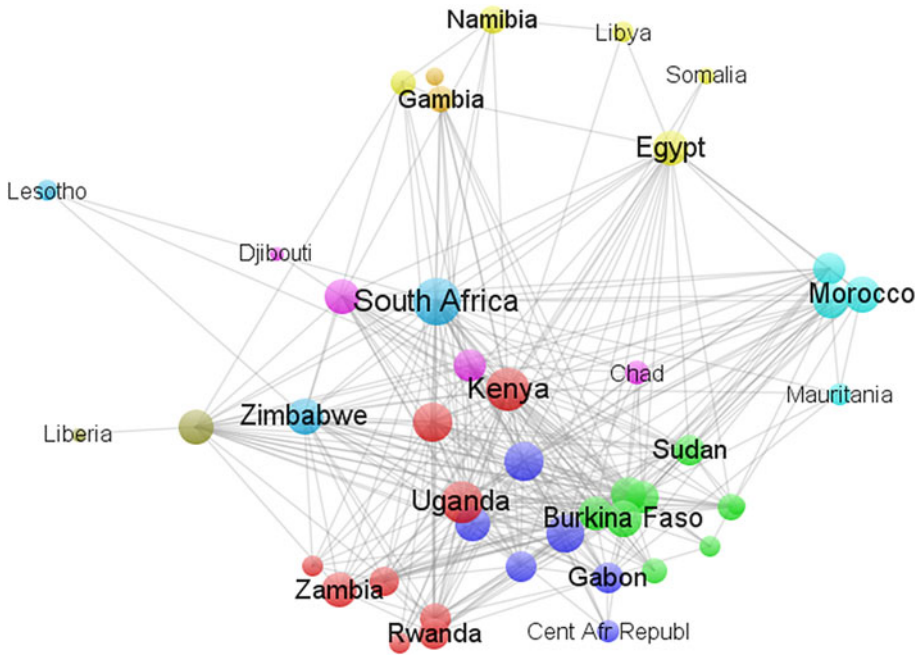

Fig. 4 Coauthorship relations between 46 countries within Africa in 2011. VOSViewer was used for the clustering and mapping. This map highlights the pivotal role of South Africa, shows the separated cluster of North Africa with Egypt as an outlier due to its wider attachments, and recognizes not only the East Africa group but also the development of two distinct groups in West Africa. The map can be web-started at http://www.vosviewer.com/vosviewer.php?map=http://www.leydesdorff.net/intcoll/afr_map.txt&network=http://www.leydesdorff.net/intcoll/afr_netw.txt&label_size=1.25&n_lines=1000 for further exploration

(1) There is a marked interaction between the countries in North Africa which share both language and culture and are also relatively prolific. Thus, this network is probably the strongest group overall since it links countries which are individually research active across multiple fields. The group does little research with the rest of Africa, however, other than through an Egypt-South Africa link.
(2) A West Africa group (Benin-Togo) pivots around Cameroon, a relatively research productive country. The common factor within this group is almost certainly their common use of French as the cross-national business language.
(3) Language also gives us the clue to the large group which includes Kenya and geographical neighbours in East Africa but also includes Nigeria, Ghana and Gambia. Those countries appear to have English as a common language or have had a strong Anglophone influence.
(4) SADC does not emerge as a research network since it is split between that group linked to Kenya and Nigeria (Bishoff 2010) and a second group most closely linked to South Africa, but which also includes Sudan and Gabon. The overall collaboration network, to the extent that one exists at all, is dependent on a small number of key players linking these regional and cultural groupings.

The simplified collaboration cartwheel of Fig. 3 is useful for managers and planners. It is expanded and developed in Fig. 4 into a complementary visualisation where completeness adds complexity requiring additional interpretation. It is therefore of greater

value for the analyst. The map highlights the pivotal role of South Africa: the research hub in every sense. The map shows that Egypt is not embedded in the separated cluster of North Africa but is an outlier due to its wider attachments. There is a strong East Africa group, as in Fig. 3, but there is also the development of two distinct groups in West Africa.

In Fig. 2, there is a difference between the countries in North Africa (Fig. 4) and those in other regions. Globally, the most frequent collaborative partner is the USA. Often this is a consequence of researchers who have studied in the USA maintaining links with those research groups when they return home. The UK, Germany and France are the other common partners to the countries featured here and this is where we see the influence of the global network (pace Wagner op. cit.).

Nigeria sits at a research crossroads between East, West and South Africa. Despite its disappointing research investment, it has a connecting role. Not only is it a part of the Anglophone collaborative network but it also links with West African neighbours and connects strongly to South Africa. South Africa is a similarly strong node with a spread of links into other groups. These two, with Kenya, create strong cross-continent links and are key nodes into global networks. In time, this may emerge as a system akin to the global model.

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