

Medical research versus disease burden in Africa

Citation for published version (APA):

Confraria, H., & Wang, L. (2020). Medical research versus disease burden in Africa. *Research Policy*, 49(3), Article 103916. <https://doi.org/10.1016/j.respol.2019.103916>

Document status and date:

Published: 01/04/2020

DOI:

[10.1016/j.respol.2019.103916](https://doi.org/10.1016/j.respol.2019.103916)

Document Version:

Publisher's PDF, also known as Version of record

Document license:

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Medical research versus disease burden in Africa

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ARTICLE INFO

Keywords:

Research priorities
Disease burden
Science policy, Africa, Research funding

JEL codes:

O30
I18
I20

ABSTRACT

Africa is a continent facing severe, urgent, and often unique health challenges. At the same time, in most African countries, national research funding is very limited and research systems are usually dependant on international research funding and collaboration. Therefore, in this context, there are worries that foreign partners will dominate medical research agendas, which may take research away from being relevant to specific local health needs. In this article, we investigate whether the distribution of medical research priorities and investment in medical research, across diseases in Africa, is related to the disease burden of local populations between 2006 and 2015. Our results show that, although African medical research capacity is still very weak and greatly dependant on public non-African and philanthropic funders, medical research specialisation in sub-Saharan Africa is generally associated with its disease burden. Our results are interesting because they indicate that although there are misalignments at the global level between research priorities and disease burden in absolute terms, in sub-Saharan Africa, there is no clear trade-off between participating in global research networks and producing medical research that is aligned with local health needs.

1. Introduction

Africa is a continent facing severe, urgent, and often unique health challenges. The region has made overall progress during the last decades in reducing mortality and prolonging life, but its burden of disease per population continues to be two times higher than that of higher-income countries.¹ At the same time, most African countries have difficulties in supporting medical research, and the pharmaceutical industry may be reluctant to sponsor research in lower-income countries because the prospects of profit are limited, even if effective treatments are developed (Taylor, 1986; World Health Organization, 2012).

Nevertheless, it has been well recognized that medical research conducted in low-income countries is of great importance (AMS-IAP, 2017). Strengthened research capacity to understand the determinants of disease in relation to gender, ethnicity, cohorts, communities and genetic distributions amongst different African populations, is crucial for local organisations to find more effective and lasting ways to improve health outcomes and health systems in the region (Ezeh et al., 2010; Juma, 2016; Mackintosh et al., 2018). Furthermore, the knowledge acquired by local scholars in this process could be diffused through different interactions with peers, students, health

professionals and society in general, which can create human capital capable of implementing and creating solutions.²

In our study, we are particularly interested in understanding the alignment between the medical research effort performed by African researchers and the burden of disease across African regions. Furthermore, since there is very little literature studying how research funding has an impact on research prioritisation on a given challenge or disease, we will also analyse the funding institutions acknowledged in their publications.

This approach is interesting for two main reasons. First, due to the tremendous health challenges the continent faces, improved Africa-relevant medical research can have an important role in changing the professional practice of health care providers and a significant impact on health outcomes. Second, our approach will allow us to evaluate whether international development funders and pharmaceutical companies are supporting research that is associated with the research needs of African regions.

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¹ <https://vizhub.healthdata.org/gbd-compare/>

² For example Carlos Chagas in Brazil discovered the parasite American trypanosomiasis (also called Chagas disease), which is a type of neglected tropical disease especially common in low-income countries (Lee et al., 2013), and Carlos Finlay from Cuba found that a mosquito transmits the yellow fever virus.

2. Background

2.1. Medical research in Africa

Total medical research output from African countries is relatively small when compared to high-income contexts (UNESCO, 2015). This is because there are relatively few researchers per capita in most African countries and the ones that exist suffer from specific challenges such as poor conditions for research personnel, heavy teaching loads, inability to mentor young scholars, inadequate infrastructure and lack of funding (Mouton, 2008; Sawyerr, 2014). However, it has been argued that the capacity of researchers and institutions in low-income regions must be strengthened in order to address their problems more effectively (Cardoso et al., 2014; Swingler et al., 2005). Researchers in African countries are best placed to identify and address the health challenges of their nations, to have a clear understanding of the local constraints and barriers to the implementation of research in practice, and to provide local and national policy-makers with a broad range of high-quality, relevant evidence to inform policy making (Guindon et al., 2010). This interaction is especially important in some African communities where target populations are sometimes socially resistant and non-adherent to medical intervention, and it has inspired educational projects to enhance the public understanding of medicine and practitioner understanding of diverse patient cultures (Aizer and Stroud, 2010).

However, from the policy side research has had an image problem, perceived as being an additional demand on overburdened services and taking many years to produce results that have little immediate relevance (Mgone et al., 2010). African countries are committed to increasing funding for science, but overall levels of funding are still low (Chataway et al., 2017; Mgone et al., 2010). According to Cardoso et al. (2014), lack of funding for research is one of the major barriers to the development of clinical research capacity in Africa. However, political, economic or socio-cultural factors like lack of policymakers' understanding of the importance and benefits of research, lack of human resources and lack of infrastructure should also be taken into account. Furthermore, they argue, "the overwhelming majority of clinical research in all 46 countries is based on funding from external donors. In the majority of cases, clinical research typically appears to be conducted in vertical 'silos', with African researchers working closely with their donors and European and US academic partners, while local governments are taking a peripheral role" (Cardoso et al., 2014, p14). On the same line, in an ethnographic study made in Eastern African, Moyo Okwaro & Geissler (2015) argue that most of their interviewed scientists stated that biomedical research in their institutions would be impossible without northern collaborators. One university director remarked: "Everything you see here has been obtained from donor funding". Except for South Africa, in most African countries, government funding appears to be limited to indirect support such as staff salaries, infrastructure and provision of subsidised equipment rather than funding specific health research programmes (Cardoso et al., 2014).

Since external criteria for funding often drive research in Africa, an important question is to understand if there is a trade-off between international scientific integration and alignment of medical research with local needs. On the one hand, by being dependant on international funding and collaboration to perform research, there is a risk that research conducted in lower-income contexts will follow topics determined by the international agenda, which may not be the same as the local health needs. On the other hand, foreign research funding has some benefits. Karim & Karim (2010), for example, argue that in South Africa having financial autonomy from the government has had three main benefits for local HIV/AIDS research communities. First, it has reduced dependence on the government, enabling scientists to challenge politicians on their HIV/AIDS denialism without fear of losing research funds. Second, it has raised the quality of local research to

international standards. Third, it has enabled South Africa to build research capacity and infrastructure, which potentially allowed the reduction of "brain-drain". Given this duality, a key governance challenge is to identify how to benefit mostly from international research partnerships and how to prioritize the limited resources that are available.

2.2. Setting priorities for medical research in Africa

According to Chataway et al. (2019) there are two main perspectives for science funding and priority setting in Africa. On the one hand, there is a set of reasons that justify science funding based on committing resources to excellent science (Tijssen and Kraemer-Mbula, 2017), as defined in traditional ways by publication in high-impact journals and international peer-review standards. Researchers that produce high-impact publications are the people who are on the cutting edge in their fields. They are performing and publishing work that their peers recognise as vital to the advancement of their field, and usually they are integrated in international networks where new ideas and technologies are often being discussed (Confraria et al., 2018). Their understanding of the research frontier can allow them to act as important conduits of cutting edge knowledge into the local academic research community (Barnard et al., 2012), that can be adapted to local contexts to tackle medical needs and help to develop policies and interventions to ultimately improve health outcomes in each region.

On the other hand, there are calls for science and research funding that is more aligned with local social and economic agendas (Sarewitz and Pielke Jr., 2007). The central idea here is that a misalignment between research priorities and societal needs may reduce the impact of investments in research to address the major challenges of society. In health, in particular, it can be argued that in resource-poor settings, available research funds must respond more directly to community health needs, and therefore be conducted according to recognised priorities. This is because higher-income countries have different health profiles from lower-income countries, and therefore use their vast resources to study diseases that are more relevant for them and less relevant for lower-income countries (Evans et al., 2014; McGregor et al., 2014; Rafols and Yegros, 2017). According to this approach, conventional peer review and assessment of academic outputs has its place in decision-making, but a range of other criteria are thought necessary.

Following this second perspective, the methods for setting priorities for health resource allocation range from qualitative methods such as consensus building with health experts and users, to the use of quantitative formulations and prioritisation matrices. Quantitative approaches, as the disability-adjusted life year³ (DALY) have gained prominence in the research priority-setting process because these measures allow for a cross-comparison amongst a broad range of diseases, regions and are particularly attractive for cost-benefit analysis.

Using this method, some research argues that there are substantial misalignments, at the global level, between research efforts and World Health Organization (WHO) estimates of health burden for a given disease (Atal et al., 2018; Evans et al., 2014; Rafols and Yegros, 2017; Røttingen et al., 2013). In our research, we will follow this approach and use DALYs in each disease field and African region as a proxy for societal needs in health, which is compared with scientific research in each corresponding disease field and region. We focus on four African regions (Eastern Africa, Northern Africa, Southern Africa or West & Central Africa) as defined by the UN classification,⁴ and our central research questions are: 1) Is the amount of research produced on various diseases by African researchers related to their countries' burden of disease? 2) What kind of medical research is being funded by different funders?

³ One DALY represents one lost year of healthy life.

⁴ https://en.wikipedia.org/wiki/United_Nations_geoscheme_for_Africa

3. Data and methods

Our analytical section is composed of two segments. In the first section, we use descriptive statistics to display the association between medical research specialisation and disease burden specialisation by African region and by disease field; and examine what type of medical research is relatively more funded by certain types of funders than others. In the second part, we further explore the research and disease association using regression analysis.

3.1. Health needs

To identify medical priorities, we use DALYs from WHO to measure the burden of disease. The DALY is a summary measure that combines time lost through premature death and time lived in states of less than optimal health. One DALY can be thought of as one lost year of healthy life, and the measured disease burden is the gap between a population's health status and that of a normative reference population (World Health Organization, 2017). The WHO estimates DALYs for 136 health conditions, which are grouped in three broad cause groups and 22 sub-groups: Group I, communicable, maternal, perinatal and nutritional conditions (5 sub-groups), Group II, noncommunicable diseases (15 sub-groups) and Group III, injuries (2 sub-groups). Since the sub-group "Infectious and parasitic diseases", in Group I, includes several diseases that are particularly harmful in some African regions (e.g. HIV in Southern Africa) we decided to expand that sub-group (with 12 diseases) to obtain a more fine-grained analysis. The sub-groups "other neoplasms", "sudden infant death syndrome", and the condition "other infectious diseases" are excluded due to ambiguity. We also exclude injuries (Group III) because we found difficult to identify scientific publications associated with injuries such as "road injuries", "falls" and "fire, heat and hot substances". As a result, we end up classifying 28 disease categories⁵: "Cardiovascular diseases", "childhood-cluster diseases", "congenital anomalies", "diabetes mellitus", "diarrhoeal diseases", "digestive diseases", "encephalitis", "endocrine blood immune disorders", "genitourinary diseases", "hepatitis", "HIV/AIDS", "intestinal nematode infections", "leprosy", "malignant neoplasms", "maternal conditions", "meningitis", "mental and substance use disorders", "musculoskeletal diseases", "neonatal conditions", "neurological conditions", "nutritional deficiencies", "oral conditions", "parasitic and vector diseases", "respiratory infections & diseases", "sense organ diseases", "skin diseases", "STDs excluding HIV" and "tuberculosis".

3.2. Research priorities

One approach to establishing priorities is to relate research investments to disease burden. While estimates of DALYs by disease have been made, estimates of investments for health problem are usually unavailable at the national level and are only limited and incomplete for international investments. Another approach is to look at scientific research output (published in medical peer-review journals) as a proxy for resources applied to a specific disease.⁶ In this article, we interpret the distribution of medical publications per disease in a given region/period, as the distribution of revealed priorities in medical research for that region/period. Although not all research and development (R&D) efforts are embodied in scientific articles, it is argued that in medical related areas scientific publications tell us more on actual applications of knowledge than publications in other fields of science (Sarewitz and Nelson, 2008). This is because, in order to start a new treatment in clinical practice, there must exist scientific evidence that the new drugs, procedures or devices work and are robust. This kind of evidence is systematically published in peer-reviewed journals (Mina et al., 2007).

The identification of publication output (articles and reviews)

comes from the WoS. We extracted each article that was produced by at least one author from an African institution, and we use the full counting method (e.g. an article done in international collaboration between UK, Kenya and Tanzania biomedical researchers would be credited to both Kenya and Tanzania). We used full counting method instead of fractional counting because we aim to investigate the extent to which African researchers participate (or are involved) in medical research in a given disease and not the weight (or influence) that they have in the research itself. We used WoS instead of Scopus or other databases because we also wanted to gather data about funding institutions mentioned in the acknowledgements of every paper and this is arguably better with WoS (Kokol and Vošner, 2018). We are aware that WoS may underrepresent journals from lower-income regions (Chavarro et al., 2017), but it is a database that is otherwise reliable and widely used for bibliometric studies.

Publication records are assigned to a specific disease field by searches in abstracts and titles. We built a set of keywords that are strongly associated to a specific disease (or group of diseases) based on the ICD-9 codes⁷ and previous research (Cardoso et al., 2014; Chapman et al., 2017; MSF, 2016). After building our queries (see Table A.1 in the appendix), two external peer reviewers⁸ reviewed the keywords for each one of our 28 disease categories.

After cleaning the publication data for entries with missing information, and limiting the analysis to 2006–2015, we are left with 59,486 documents that were associated to at least one specific disease (28) and one African region (Eastern Africa, Northern Africa, Southern Africa or West & Central Africa).

3.3. Indicators

With the hypothesis that health needs in earlier years should drive the research agenda in later years, we compare the number of articles published between 2011–2015 with the disease burden in 2010. First, we count DALYs in each disease per region/period and number of publications in each disease per region/period. Then, since different diseases have different propensities to affect people and be researched, we also compute specialisation indices, including both scientific research specialisation (SI_{Pub}) and disease burden specialisation (SI_{DALY}), to assess the specialisation of each disease in a given region. We do this by calculating the revealed comparative index (Balassa, 1965). The scientific research specialisation (SI_{Pub}) can be expressed as follows:

$$SI_{Pub}_{rd} = \frac{P_{rd} / \sum_d P_{rd}}{P_d / \sum_d P_d} \quad (1)$$

where P is the number of publications in region r in disease d . This index can be interpreted as a "comparative advantage". If region r has a higher relative publication specialisation in disease d , it means that region r has more scientific research focused on disease d than the world average ($SI_{Pub} > 1$). Likewise, based on DALYs data, we also calculate the disease burden specialisation index in each region:

$$SI_{DALY}_{rd} = \frac{D_{rd} / \sum_d D_{rd}}{D_d / \sum_d D_d} \quad (2)$$

where D is the number of DALYs in region r in disease d . Similar to Eq. (1), if region r has a higher relative disease intensity in field d , it means that region r has more health problems related to disease d than the world average ($SI_{DALY} > 1$).

The definition of the above indices implies that their values are

⁷ <http://icd9.chrisendres.com/>

⁸ One of the reviewers is a PhD student in international health and development, who worked for five years as a nurse in epidemic contexts in several African countries. The other is a nurse with 15 years of experience and a MSc in health economics.

⁵ Please see Table A.1 in appendix for more details about our classification.

⁶ Ciarli and Ráfols (2018) use an identical approach for rice research.

necessarily null or positive but are not bound by an upper limit. For this reason, we standardise this measure as follows:

$$NSI_Pub = \frac{(SI_Pub - 1)}{(SI_Pub + 1)} \quad (3)$$

and

$$NSI_DALY = \frac{(SI_DALY - 1)}{(SI_DALY + 1)} \quad (4)$$

The threshold value of the normalised specialisation indices remain zero, but the asymptotic limits are now ± 1 .

In order to analyse the research being funded by a certain institution in a given disease or region, we use the acknowledgement paratext of scientific publications in WoS where authors commonly give thanks to the funding agencies (e.g. Costas and Leeuwen, 2012; Grassano et al., 2017; Rigby, 2011). In our case, we focus only on publications from 2009⁹ to 2015, and we separate them into two groups (2009–2010 and 2011–2015).¹⁰ We use VantagePoint and manual searching methods to group different name variations for the same funding institution mentioned in the acknowledgements section of our sample of publications. After cleaning name variations of funding organisations, we focus on those sponsoring medical research in Africa with more than 30 publications (showing more than 0.05% of times) between 2009 and 2015. Besides calculating the number of publications with acknowledgements to a specific funding institution by disease and region, we also group each funding institution in five group types based on the G-finder classification¹¹: 1) African public funding; 2) Non-African public funding; 3) Multilateral funding; 4) Philanthropic funding and 5) Corporation funding. Subsequently, we calculate the normalised relative specialisation index (NSI), following the steps explained before, for each funding group on 2011–2015 and 2009–2010 by disease and region.

3.4. Econometric approach

In this study, our primary research question is to understand whether disease burden relative specialisation is associated with medical research specialisation between different African regions across different diseases. To address this, in our multivariate regression analysis (OLS), we use scientific specialisation (NSI_Pub) as our dependant variable, and disease burden specialisation as our main independent variable. Since most African countries are highly dependant on international (non-African) research collaboration, in our model we control for the level of international collaboration. We also control for previous scientific specialisation due to the path-dependant nature of scientific production.

In our Eq. (5), NSI_Pub is the scientific specialisation index in a certain region r , disease field d and period t (2011–2015). NSI_DALY is the disease burden specialisation index in period $t-1$ (2010). IC is the percentage of internationally co-authored publications, L_NSI_Pub is a lagged dependant variable from the previous period (2006–2010), and R is a control for each of the four African regions. Finally, α is the constant, and ε is the unobserved residual.

⁹ WoS only provides systematic information from the funding text of acknowledgements for publications since August 2008.

¹⁰ According to Costas & Leeuwen (2012) two important limitations must be taken into account when working with this source of information: 1) WoS funding information is dependent on the algorithm developed by Thomson Reuters, which may not be applied systematically in all journals, for all publications, for all disciplines, etc. 2) Second, an important conceptual limitation is that acknowledgements are a voluntary activity. Hence, authors can also decide not to acknowledge funding, or forget to do so.

¹¹ <https://gfinder.policycuresresearch.org/PublicSearchTool/>

$$NSI_Pub_{rd} = \alpha + \mu NSI_DALY_{rd} + \varphi IC_{rd} + L_NSI_Pub_{rd} + R_r + \varepsilon_{rd} \quad (5)$$

Since we are also interested in understanding if international funders are supporting medical research that is relevant for the health needs of African regions, we also compute a set of regressions that estimate what the relation between disease burden relative specialisation and research funding relative specialisation by donor category is. We conduct this analysis by using five different types of donor categories (dependant variables): 1) African public funding; 2) Non-African public funding (including multilateral funding); 3) Philanthropic funding; 4) Corporation funding; and 5) Non-funded research (or not identified).

$$NSI_FundCat_{rd} = \alpha + \mu NSI_DALY_{rd} + \varphi IC_{rd} + L_NSI_FundCat_{rd} + R_r + \varepsilon_{rd} \quad (6)$$

In Eq. (6), $NSI_FundCat$ is the specialisation index (for each of the five funding categories) in a certain region r , disease field d and period t (2011–2015), and $L_NSI_FundCat$ is a lagged dependant variable from the previously available period (2009–2010). The remaining variables (NSI_DALY , IC , R and α) are the same as those in Eq. (5).

4. Results

4.1. Descriptive analysis

As discussed before, there are vast imbalances in global medical research between Africa and higher-income regions. Our analysis reveals that, between 2006 and 2015, the estimated world share of scientific output in medical research (28 diseases) by African researchers accounted to only 2.1%, a marked contrast to the fact that almost 28% of the global disease burden in the same diseases was in Africa in a similar period.¹² Fig. 1 shows the world proportion of medical research, disease burden and population across African regions between 2006 and 2015. This mismatch is especially remarkable for Eastern Africa and West & Central Africa where the disease burden world share is 16 and 29 times higher than the research share, respectively. Southern African is the region where this mismatch is smaller (less than 3 times), while Northern Africa is the only African region where the population world share is higher than their disease burden share.

In all African regions, the world medical research share is smaller than their world population share. However, we found that medical research has increased in all regions more than 50%, between 2006–2010 and 2011–2015. The condition with more publications in each region is “parasitic and vector diseases” in Eastern and Western & Central Africa, “malignant neoplasms” in Northern Africa and “HIV/AIDS” in Southern Africa.

As for DALYs we find that the countries with the highest incidence per capita by African region in 2015 are: Sudan (0.44 DALYs per capita) for Northern Africa; Lesotho (0.71 DALYs per capita) for Southern Africa; Angola (0.95 DALYs per capita) for West & Central Africa and Somalia (0.88 DALYs per capita) for Eastern Africa. DALYs per capita are decreasing on average in all regions, but the most negative growth rates were in Eastern and Western & Central Africa.

4.1.1. Disease burden specialisation vs. research specialisation

To further assess the association between research output and disease burden in each African region, we created three complementary graphs (Fig. 2, Fig. 3 and Fig. A.1) that display the relation between disease burden and medical research in 28 diseases, using different approaches. In Fig. 2 we calculate the normalised specialisation indices for each disease using Eq. (3) for publications and Eq. (4) for DALYs. These indices focus on the deviation of a region's medical research and disease burden specialisation from the average world specialisation

¹² Average of DALYs share in 2005, 2010 and 2015.

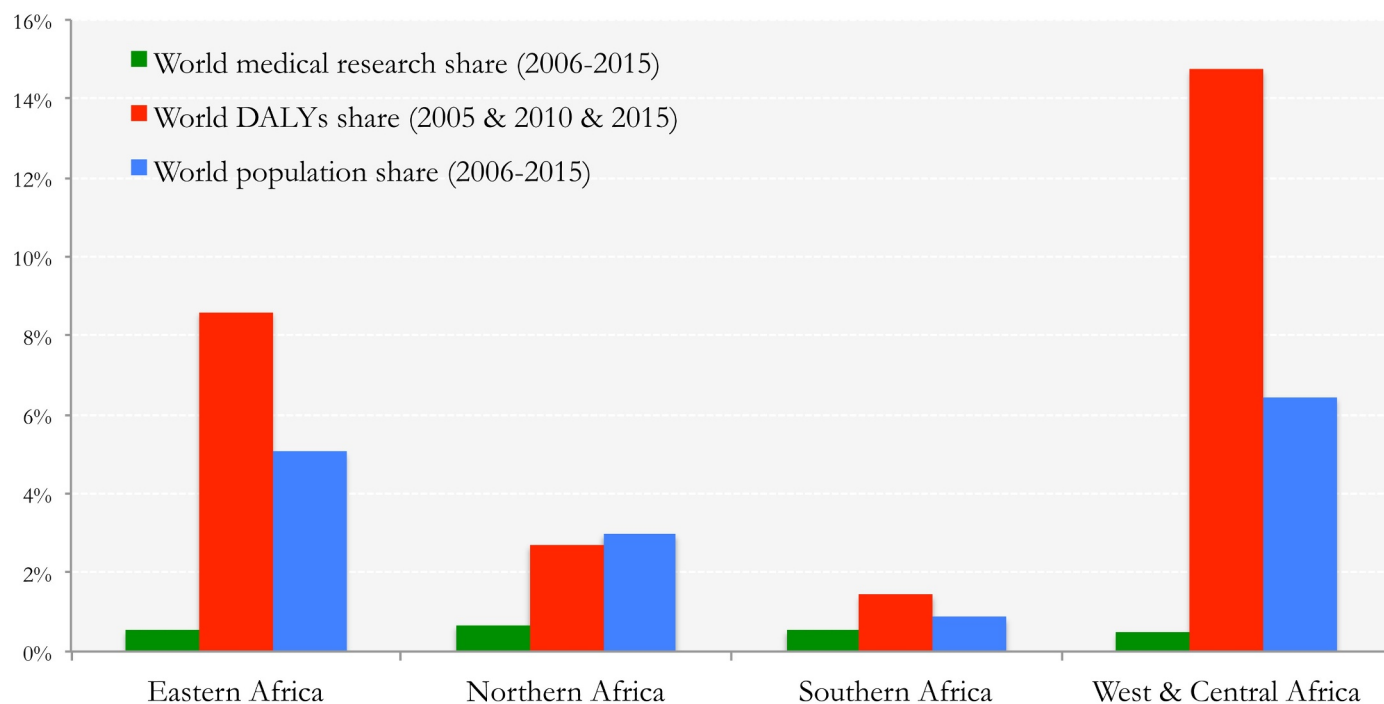


Fig. 1. World share of disease scientific production, disease burden and population across African regions.

Note: In this chart, the numbers presented are yearly averages between 2006 and 2015. DALYs data only was available for 2005, 2010 and 2015. For the medical research output and the DALYs, the calculation only takes to account the 28 diseases identified (Group I and II diseases).

Source: Own calculation based on WoS, WHO and Worldometers.

levels. The further away an observation (disease) is from the centre, the further away is the specialisation pattern of a region in that disease from the world average.

We observe that Eastern Africa and West & Central Africa exhibit a strong positive association between the two dimensions. In these two regions, the diseases that generate higher relative burden (e.g. “maternal conditions”, “parasitic and vector diseases”, “HIV/AIDS”) are also the ones that researchers in these regions are relatively specialised. On the other extreme, non-communicable diseases such as “malignant neoplasms” and “diabetes” generate little disease burden and research in both regions, compared to the world average.

This positive association is not so clear for Southern Africa and especially for Northern Africa. In these regions, there are some diseases like “parasitic and vector diseases” and “leprosy” that display a low level of disease burden specialisation but a high level of scientific specialisation. One could argue that these topics are “over-researched” since the disease burden in these regions is not relatively high. However, since in 2015 globally, 4 out of 5 DALYs in “parasitic and vector diseases” are from Africa, due to the high disease burden in the Eastern Africa and West & Central Africa, this high level of scientific specialisation may be justified by the existence of research tradition in these areas, promotion of intra-African research collaborations and the development of research capacities in other African regions. As for leprosy, since it is considered a neglected disease, with residual impact in high-income countries, the existence of scientific capabilities in these regions may also be justified.

Another interesting finding is that in all African regions “tuberculosis” is a topic of high scientific specialisation. Since the risk of developing tuberculosis is estimated to be between 16–27 times greater in people living with HIV than amongst those without HIV infection,¹³ the high levels of scientific specialisation in “tuberculosis” are probably because in most countries HIV/AIDS research is done in conjunction

with tuberculosis research. In South Africa, for example, most patients who die from HIV-related causes die from tuberculosis or similar illnesses.

Finally, we do not find any region where a disease with a relatively high burden (NSI DALYs > 0.5) is not a scientific priority (NSI Pubs > 0.0). The only diseases that could be seen as “under-researched” are the ones that are between 0 and 0.5 in the x-axis (NSI DALYs) and between –0.5 and 0 in the y-axis (NSI Pubs) in every region. Some examples include “diabetes” in Southern Africa and “diarrhoeal diseases” in Eastern Africa.

It is worth noting that the indices in Fig. 2 were calculated based on the comparisons with world-wide average specialisation levels. We used the world level as a benchmark because, on average, the amount of publications produced by authors in different fields varies substantially, and a direct comparison using absolute levels may lead to bias.¹⁴ However, to access the robustness of our findings, we used two other methods to plot research production as a function of disease burden. In Fig. 3 we display the total disease burden (x-axis) versus the total number of publications (y-axis) in each disease (in logarithms), and in Fig. A.1 (in appendix) we show the share of disease burden (x-axis) versus the share of publications (y-axis) in each disease (%).

In Fig. 3, all graphs show a slight positive correlation between disease burden and scientific output. This means that, on average, the higher the disease burden of a disease in a region, the higher the number of publications produced on that disease by researchers in that

¹⁴ For example, “Neonatal conditions” is an area that generates a relatively big share of disease burden in the world (~10% of total DALYs in 2010) but a low share of research (< 1% of total medical research). This doesn't necessarily mean that there is little research in the world on “Neonatal conditions”. One could argue that to decrease the disease burden in this area what is preferable or more efficient than doing more basic research, is a better health care system, available hospitals and better health conditions/support in the most affected regions. Hence, a direct look at absolute levels of publications versus absolute levels of DALYs may be misleading.

¹³ <http://www.who.int/hiv/topics/tb/en/>

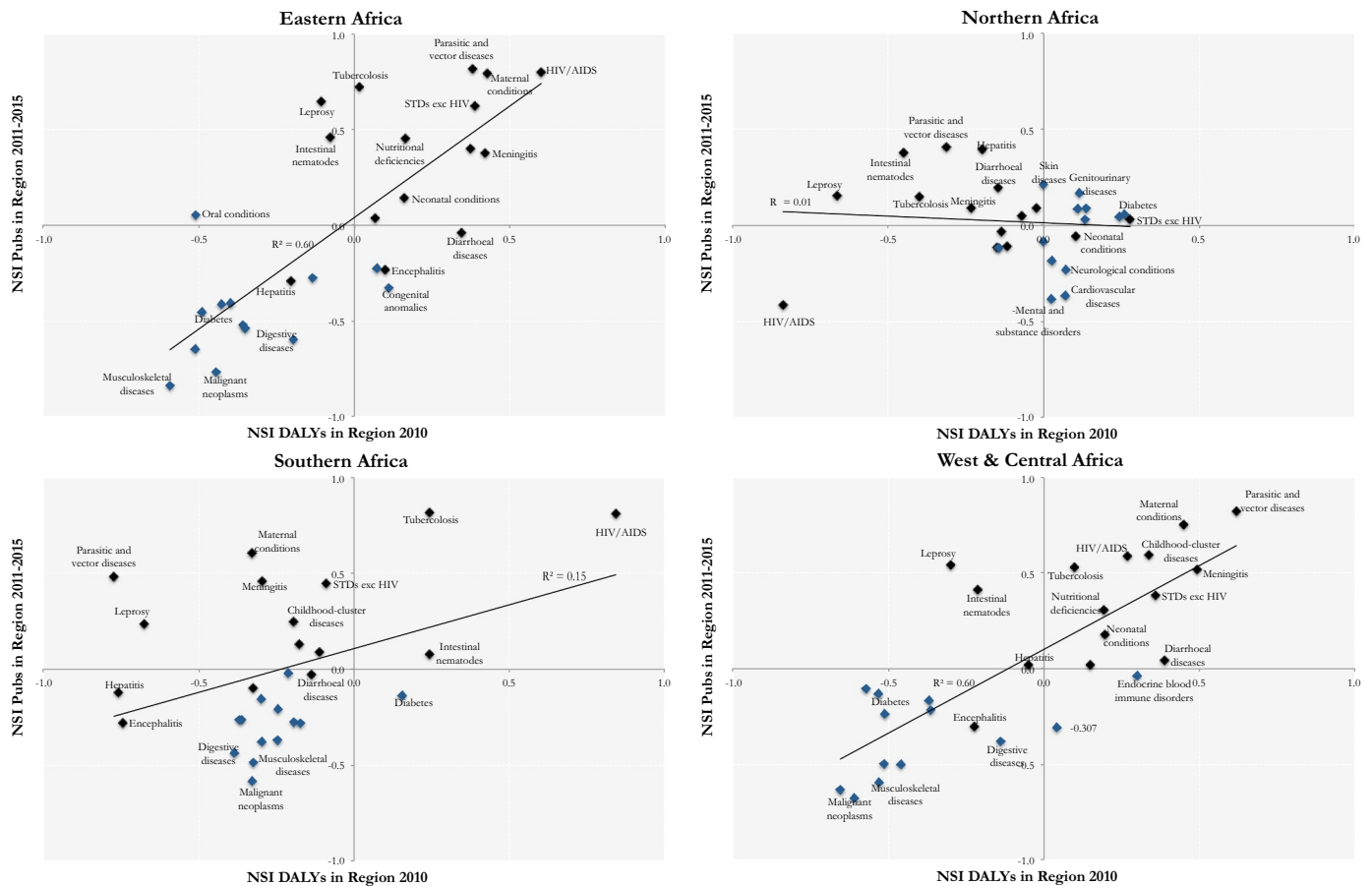


Fig. 2. Disease burden specialisation vs research specialisation by disease.
Note 1: DALYs from 2010 and scientific publications from 2011–2015.
Note 2: Black dots show Group I diseases (communicable, maternal, perinatal and nutritional conditions). Blue dots show Group II diseases (non-communicable).
Source: Own calculation based on WoS and WHO.

region. The same association was not found in Fig. A.1. There we can observe some outliers like HIV/AIDS in Southern Africa. It represents around 43% of the total disease burden of the region in 2010 and 19% of the total medical scientific output. South Africa accounts for a third of all new HIV infections in Southern Africa, and it has the highest profile HIV epidemic in the world, with an estimated 7.1 million people living with HIV in 2016 (UNAIDS, 2017). The region has made progress in reducing the disease burden associated with this disease since 2005, but it is still a huge issue. It is argued that in South Africa important research is being done on developing HIV vaccines, yet little attention is being paid to planning approaches to reduce the high rates of infection amongst young women, the primary driver of HIV epidemic in the country (Karim and Karim, 2010).

This reminds us that there are different kinds of research approaches to solve disease burden. One approach is to find solutions from conducting laboratory tests (to discover biological causes and develop preventive and curable medicines). In other cases, it may be more beneficial to put more effort into studying prevention mechanisms and reducing lifestyle risks (e.g. unhealthy eating style or smoking). In others, what may matter is to understand how to improve infrastructural conditions and social environment (e.g. providing clean water) (Cassi et al., 2017; Lalonde, 1974). Compared with the biological causes of diseases, lifestyle and social environment are relatively less covered by scientific publications. For instance, in the field of

obesity, 70%–90% of the total publications are related to medical disciplines and biology, and very few are related to other factors such as health risk, lifestyles and social environment (Cassi et al., 2017). Since in our paper, we are only able to identify if a paper is about a disease and not what kind of research it is (e.g. biomedical or public health), we cannot say much about priority setting of approaches to diseases.

What we can put forward is that the combination of Fig. 2, Fig. 3 and Fig. A.1 provides information from different angles to understand the alignment between disease burden and research priorities in the different African regions. What we find is that when we use indicators that diminish the influence of outliers (Fig. 2 and Fig. 3) we observe a certain level of alignment between research priorities and disease burden in almost all regions. The exception is Northern Africa in Fig. 2. From the four African regions, it is the only region where the population world share is higher than the disease burden world share, and it is also the only African region where non-communicable diseases, which usually are associated with high-income countries like “diabetes”, “cardiovascular diseases” and “malignant neoplasms” are high absolute problems. At the same time, Northern Africa has a relatively high amount of research on communicable diseases like “hepatitis”, “tuberculosis” and “parasitic and vector diseases” that are usually more problematic in low-income countries. Therefore, this region seems to have a “high-income” disease burden profile, but a “low-income” research priority profile. Such misalignment can be interpreted as a

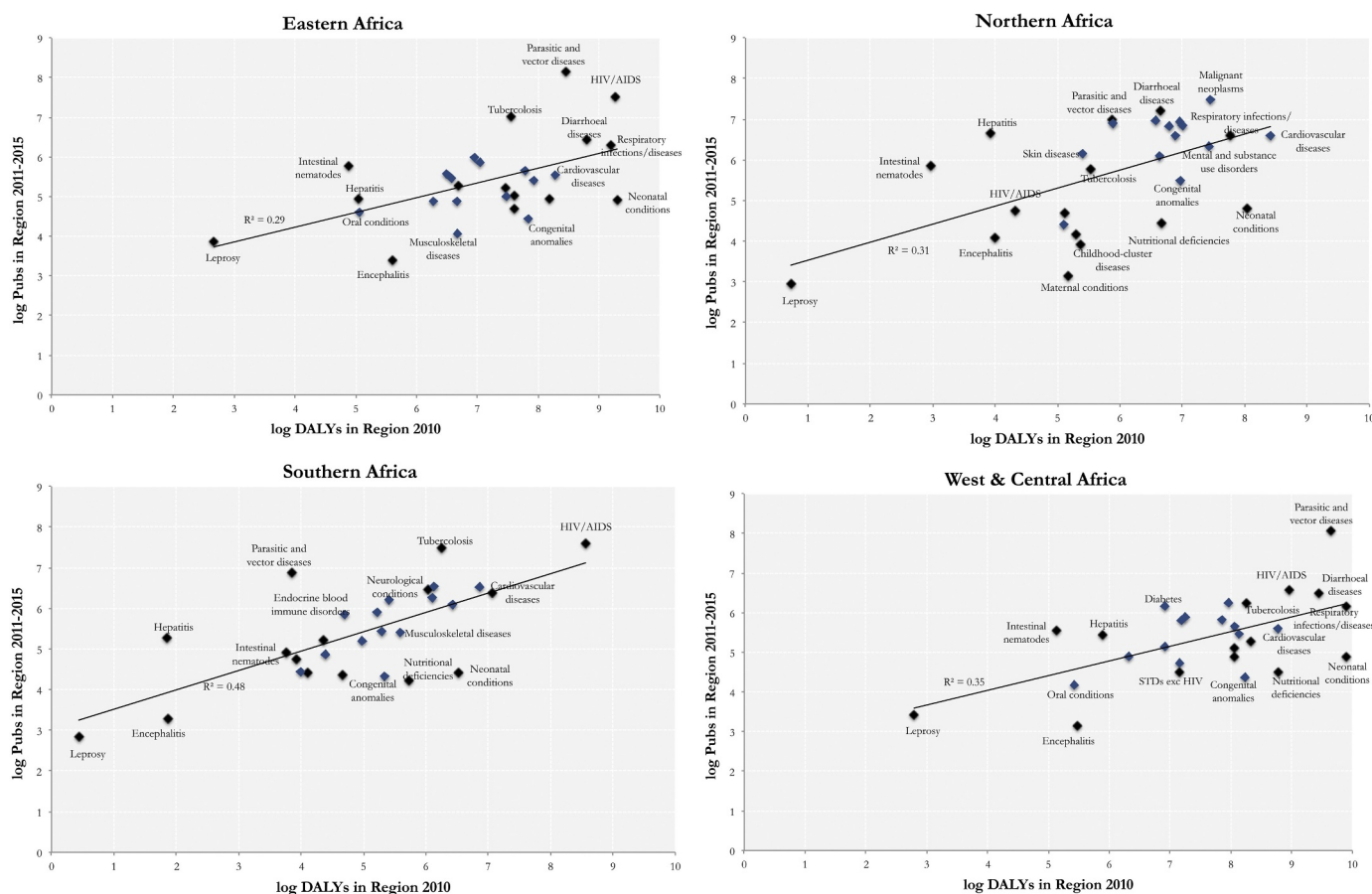


Fig. 3. Disease burden (log) vs research production (log) by disease
Note 1: DALYs from 2010 and scientific publications from 2011–2015.
Note 2: Black dots show Group I diseases (communicable, maternal, perinatal and nutritional conditions). Blue dots show Group II diseases (non-communicable).
Source: Own calculation based on WoS and WHO.

"positive" misalignment since the research being produced can potentially be of relevance for their African neighbours.¹⁵

Finally, when we use shares as an indicator (Fig. A.1), we can observe that there are certain conditions in Eastern Africa, Southern Africa and West and Central Africa that display a substantially higher absolute level of disease burden and research prioritisation. To further explore these outliers, in the next section, we study who is funding medical research in Africa.

4.2. Funded medical research in Africa

In the last thirty years, several international funders of medical research and development such as the World Health Organization (WHO), National Institutes of Health (NIH), the European Union (EU), the Bill & Melinda Gates Foundation (Gates Foundation) and the Wellcome Trust, as well as institutions supported by government funding, have all embarked on initiatives to help improve the research capacity, research environment and provide institutional support across the continent (Jones et al., 2007; Whitworth et al., 2008). In this section, we explore the different contributions of various funding organisations to medical research in Africa. Fig. 4 displays the share of publications in each region by funding type between 2011 and 2015. The sum of shares is bigger than 100% because we used the full counting method (some publications acknowledge different funding types and in our analysis they are counted as one publication for each type). The

share of the total medical research with no funding info in each African region, across the disease categories, ranged from 63% in Northern Africa to 21% in Eastern Africa. The low proportion of publications that acknowledge funding in Northern African countries was also discussed in Kozma et al. (2018) and may derive from the relatively low levels of foreign research funding and international collaboration in the region.

Since we used a threshold to identify funding institutions (see Section 3.3), there is a share of research that we know has funding acknowledgements but we don't know what institution (and type) it is. It ranges from 19% of total research in Eastern African to 12% in Southern Africa. Therefore, it is important to keep in mind that this analytical section focuses on the major funders and not on the entire spectrum of research funders in Africa.

The highest share of research funding in all regions is from public non-African funding institutions (e.g. NIH, EU, USAID, Medical Research Council (UK)), followed by Philanthropic funding institutions (e.g. Wellcome Trust, Gates Foundation) that make particularly relevant contributions in Eastern African countries. Public African funding institutions have higher shares of funding in Southern Africa (e.g. National Research Foundation (ZA), Medical Research Council (ZA)) and Northern Africa (e.g. Tunisian Government, Egyptian government and the Centre National pour la Recherche Scientifique et Technique in Morocco).

Southern Africa is the region where the contribution of corporate research funding is relatively higher (7.7% compared with 3.7% in Eastern Africa, 3.4% in West & Central Africa and 1.8% in Northern Africa). Pharmaceutical producers like GlaxoSmithKline, Pfizer and Novartis were the top funders in this category and were acknowledged

¹⁵ We thank a referee for this point.

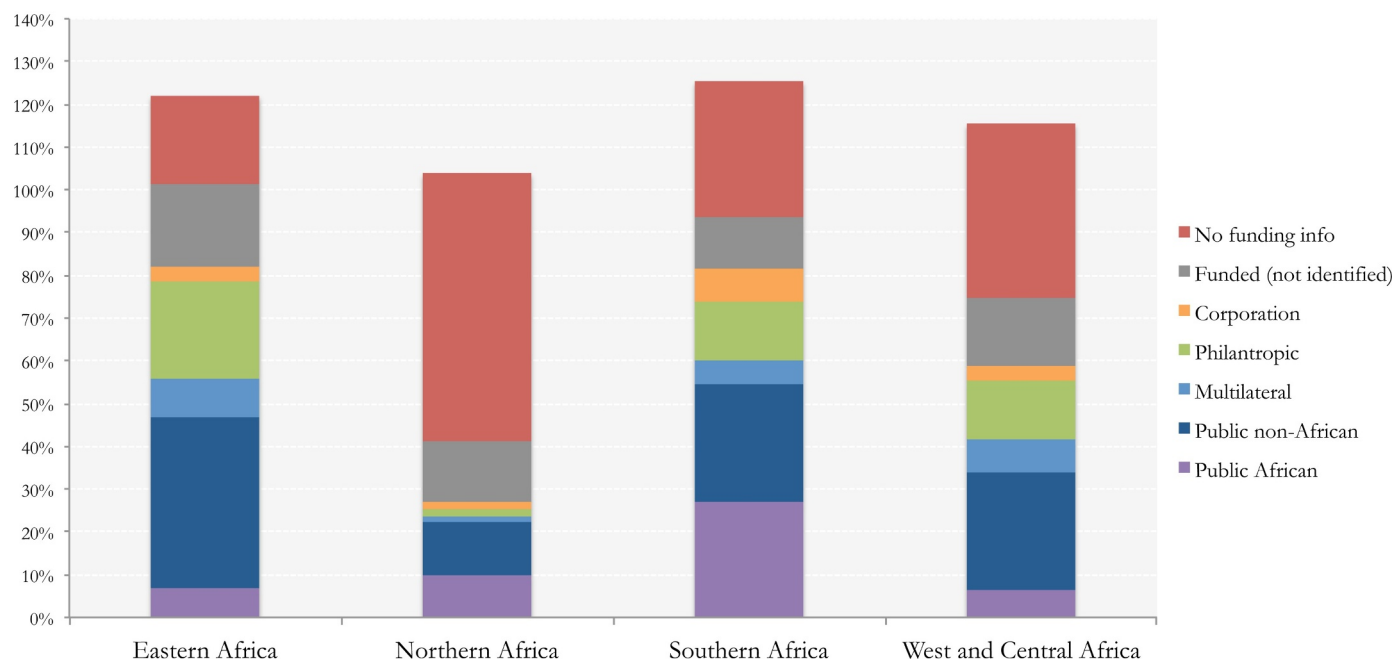


Fig. 4. Share of publications by funding type (2011–2015)

Note: The category “no funding info” represents the total amount of publications in each region that didn't have funding acknowledgements. The category “Funded (not identified)” represents the total amount of publications in each region that have funding acknowledgements but we couldn't identify who the funder(s) is (are). Source: Own calculation based on WoS.

in 328, 302 and 238 publications, respectively, in all African regions (<1% of total output in Africa). An interesting result is that on average in Africa, there seems to exist minor overlap between corporate funding and public African funding (15%), compared to substantial overlap between corporate funding and public non-African funding (42%).

Multilateral funding institutions like WHO, EDCTP and the World Bank are mostly funding medical research in Eastern African countries and West & Central African countries (See Tables A.2 and A.3 in the appendix for more info about the major contributors in each funding category and region). While doing this analysis, we also find a significant overlap between public non-African and multilateral funding (around 50% of all publications with multilateral funding also acknowledge a public non-African funder). Since theoretically, it is difficult to distinguish what are the different motivations that lead public non-African and multilateral institutions to fund African medical research, further analysis in this article will consider the two categories as the same category (public non-African).

4.3. Research specialisation of funders

We are also interested to know if each funder (or group of funders) supports research in specific diseases. Table 1 and Table 2 highlight the top 20 research funders in Africa by disease between 2011 and 2015. In Table 1, we calculated the percentage of publications supported by a specific funder in a specific disease in relation to the total amount of publications supported by that funder in Africa. In Table 2, we divide the same numerator by the total amount of publications in a specific disease in Africa, to analyse the importance of each funder in each disease. Finally, in Table 3, we analyse the research specialisation of each funder group in each African region by disease. All three tables are ordered by the number of publications in each disease in Africa.

One key finding in Table 1 and 2 is that “Parasitic and vector diseases”, “HIV/AIDS” and “Tuberculosis” are a priority for most top20 funders. These results are in line with Chapman et al. (2017) that also found that three diseases – HIV/AIDS, malaria and tuberculosis – collectively received more than two-thirds (\$2247 m, 70%) of all global funding for neglected disease R&D in 2016.

The only funders that are not so biased towards these three diseases are the National Research Council (in South Africa), Medical Research Council (in South Africa), Tunisian Government, GlaxoSmithKline and Pfizer. These are all African funders and corporations that may have different priorities than international organisations.

It is, however, important to notice the absence of Public African funders from Eastern Africa and West & Central Africa. In these regions, the importance of international funders such as the NIH, Wellcome Trust, Gates Foundation and the EU to fund medical research is very high. Interestingly, Gates Foundation funds more than 10% of African research on “neonatal conditions” which is the disease with the highest absolute disease burden in Eastern Africa and West & Central Africa. It has been argued that Gates Foundation investment has tried to balance the public sector focus on basic research (Chapman et al., 2017). According to G-finder data, it has provided 55% of all funding to neglected diseases in the world to product development partnerships and 47% of all funding for platform technologies between 2007 and 2016.

In Table 3, we combine all this information in a matrix that displays the share of medical research funded by each group of funders in each African region. This is calculated by dividing the number of publications funded by a specific funder group in a disease in a region, by the total number of publications funded by that funder group in that region. We also show the total share of publications and DALYs in each region by disease to compare the research specialisation of each funder group with the research priorities and disease burden in each region.

In Northern Africa, we can observe that there are some low burden diseases like “intestinal nematode”, “tuberculosis” and “parasitic and vector diseases” that receive a relatively high amount of funding from public African, public non-African and philanthropic groups.

Overall, public non-African and philanthropic groups fund similar diseases, and in “Eastern Africa”, “Southern Africa” and “West & Central Africa” they are mostly focused on medical research in “parasitic and vector diseases”, “tuberculosis” and “HIV/AIDS”. The share of total funding from philanthropic and public non-African institutions to “parasitic and vector diseases” is particularly high in “West & Central Africa” and “Eastern Africa”. It represents more than 40% of the total funding of these institutions in both regions. “Parasitic and vector

Table 1
Share of research supported by each funder by disease.
Source: Own calculation based on WoS.

Disease / Institution	NIH_US	Wellcome_Trust	NRF_ZA	Gates_Foundation	EU	Fogarty_Int_Center	MRC_ZA	WHO	USAID	CDC_US	NIAID_US	MRC_UK	Tunisian_Gov	DFID_UK	EDCTP	GlaxoSmithKline	Univ_Cape_Town	DST_ZA	PEPFAR_US	Pfizer	Total
Parasitic and vector diseases	30%	48%	18%	55%	41%	23%	14%	50%	30%	25%	40%	36%	9%	45%	33%	16%	25%	34%	7%	11%	7996
HIV/AIDS	26%	16%	14%	16%	8%	31%	15%	11%	32%	37%	33%	17%	0%	15%	22%	12%	16%	20%	59%	14%	4230
Tuberculosis	21%	20%	17%	10%	18%	26%	22%	9%	27%	21%	21%	20%	4%	12%	50%	5%	18%	18%	37%	7%	3402
Diarrhoeal diseases	3%	3%	12%	8%	4%	3%	4%	7%	4%	9%	3%	2%	17%	7%	2%	7%	4%	10%	1%	4%	3079
Malignant neoplasms	5%	1%	7%	0%	3%	4%	4%	1%	0%	2%	1%	2%	12%	0%	1%	5%	4%	4%	2%	3%	2721
Resp. infections/diseases	4%	8%	5%	7%	4%	3%	7%	7%	5%	8%	2%	8%	5%	3%	1%	27%	5%	5%	2%	19%	2183
Diabetes mellitus	2%	3%	6%	1%	4%	2%	8%	4%	1%	1%	0%	7%	11%	4%	2%	3%	4%	1%	1%	7%	2150
Endocrine blood immune disorders	5%	6%	3%	3%	4%	6%	3%	1%	3%	5%	5%	6%	9%	5%	5%	3%	3%	1%	3%	8%	2144
Neurological conditions	4%	5%	6%	1%	4%	5%	5%	2%	1%	1%	2%	3%	6%	4%	1%	3%	10%	1%	1%	3%	2000
Genitourinary diseases	3%	1%	3%	1%	2%	3%	4%	2%	2%	1%	2%	3%	6%	1%	2%	3%	4%	0%	1%	6%	1967
Cardiovascular diseases	3%	2%	8%	1%	3%	4%	14%	3%	1%	1%	0%	6%	9%	1%	0%	5%	11%	3%	1%	10%	1814
Mental and substance use disorders	5%	3%	5%	1%	5%	8%	11%	5%	1%	1%	2%	4%	3%	6%	2%	17%	10%	6%	2%	22%	1733
Digestive disease	1%	1%	2%	2%	1%	1%	1%	4%	0%	1%	1%	1%	2%	1%	0%	4%	1%	0%	1%	1%	1490
Hepatitis	2%	1%	3%	1%	3%	2%	2%	1%	2%	1%	2%	2%	2%	1%	2%	4%	1%	2%	2%	2%	1296
Musculoskeletal disease	1%	1%	2%	1%	1%	1%	4%	1%	0%	0%	0%	2%	4%	1%	0%	3%	1%	0%	0%	10%	1088
Intestinal nematode	2%	4%	3%	2%	3%	2%	0%	4%	2%	3%	1%	4%	6%	2%	1%	2%	0%	2%	1%	1%	1017
Sense organ diseases	1%	2%	1%	1%	1%	0%	1%	1%	0%	0%	0%	0%	5%	0%	0%	1%	1%	0%	0%	1%	888
Skin diseases	1%	2%	2%	0%	1%	0%	0%	1%	1%	0%	0%	1%	3%	2%	1%	1%	0%	1%	0%	1%	837
Meningitis	3%	4%	3%	3%	1%	4%	2%	3%	3%	3%	2%	4%	1%	1%	1%	4%	2%	2%	3%	6%	599
Congenital anomalies	1%	0%	0%	0%	1%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	470
STDs exc HIV	3%	2%	0%	3%	1%	1%	0%	1%	3%	3%	2%	3%	1%	4%	4%	1%	1%	0%	6%	1%	424
Neonatal conditions	1%	1%	0%	3%	1%	1%	1%	2%	2%	1%	1%	1%	0%	1%	1%	0%	0%	0%	0%	0%	392
Maternal conditions	0%	1%	0%	2%	0%	0%	1%	4%	2%	0%	0%	1%	0%	4%	0%	0%	1%	0%	2%	0%	380
Childhood-cluster diseases	1%	1%	1%	2%	3%	1%	0%	5%	1%	7%	0%	2%	0%	2%	0%	2%	0%	1%	1%	1%	354
Nutritional deficiencies	1%	1%	0%	1%	1%	1%	1%	1%	2%	1%	0%	2%	1%	1%	0%	1%	0%	0%	0%	0%	347
Oral conditions	0%	0%	0%	0%	1%	0%	0%	1%	1%	0%	1%	1%	0%	1%	0%	0%	0%	1%	0%	0%	311
Encephalitis	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	86
Leprosy	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	78
Total	3317	1756	1404	1381	1034	735	722	710	701	499	460	450	402	376	374	328	324	305	303	302	

diseases” group includes diseases such as malaria, dengue, trachoma, yellow fever, rabies, chagas disease, amongst others. Malaria is by far the condition that leads to higher disease burden in this category. According to Head et al. (2017), global research funding for malaria in sub-Saharan Africa is mostly allocated to Tanzania, Uganda, Kenya, Malawi, Ghana, and Nigeria. These are locations with a track record of success in similar projects where it is perceived that investments will make a positive difference and where any research will be feasible. The research supported by corporations is substantially higher in absolute terms in Southern Africa, and in areas such as “diabetes”, “cardiovascular diseases”, “respiratory infections/diseases” and “mental and substance use disorders”.

4.4. Econometric analysis

In this section, we present the results of the estimation of Eq. (5). We pool data from the period 2011–2015 for research specialisation and 2010 for disease burden specialisation. We aggregate the publication records into four African regions and 28 diseases, and constrain the database to diseases in regions with a minimum of 50 publications (to avoid outliers when computing the NSI). Table 4 shows that the Eastern African region is the region where the association between disease burden and research specialisation is highest. The region is highly dependant on international research collaboration (Confraria and Godinho, 2015) and, as we have seen in Fig. 4, it is also the region which is most dependant on funding from non-African partners and philanthropic institutions. Therefore it is interesting to notice that it is the region where the disease burden and medical research

specialisation show a greater alignment.

In Table 4, we can also observe that the disease burden specialisation in Southern Africa and West & Central Africa are also positively and significantly associated with their research specialisation in models 1, 2 & 3. However, when we include the lagged dependant variable (L_NSI_Pub) in the model, the significance disappears. This means that the association between these two dimensions may be derived mostly from the existence of previous scientific capabilities in those areas and not so much from the awareness of the disease burden in their region.

In this regard, it is important to note that there is a high correlation between NSI in 2011–2015 and previous scientific specialisation in 2006–2010 in all regions (around 98%). Scientific activities are dominated by strong path-dependencies. If one country has scientists that are involved in a certain type of research, it is very likely that they will continue to do their research in that area.

Finally, we also find that all African regions also seem to be specialised in areas where they have higher levels of international collaboration. Since the research in most African countries is highly dependant on international research collaboration and international research funding, this was an expected result.

In Table A.4, in the appendix, we also run a set of regressions that include the same model. However, instead of using normalised specialisation indices as dependant and independent variables, we use the logarithmic number of publications of each funder in a disease and region as the dependant variable, and logarithmic number of DALYs as the main independent variable. The results are similar to those in Table 4. When controlling for all the other variables, the only region where there is a positive and significant association between disease

Table 2
Importance of the top 20 funding institutions by disease in Africa.

Disease / Institution	NIH_US	Wellcome_Trust	NRF_ZA	Gates_Foundation	EU	Fogarty_Int_Center	MRC_ZA	WHO	USAID	CDC_US	NIAD_US	MRC_UK	Tunisian_Gov	DFID_UK	EDCTP	GlaxoSmithKline	Univ_Cape_Town	DST_ZA	PEPFAR_US	Pfizer	Total
Parasitic and vector diseases	13%	11%	3%	9%	5%	2%	1%	4%	3%	2%	2%	2%	0%	2%	2%	1%	1%	1%	0%	0%	7996
HIV/AIDS	20%	7%	5%	5%	2%	5%	3%	2%	5%	4%	4%	2%	0%	1%	2%	1%	1%	1%	4%	1%	4230
Tuberculosis	21%	10%	7%	4%	5%	6%	5%	2%	6%	3%	3%	3%	0%	1%	5%	0%	2%	2%	3%	1%	3402
Diarrhoeal diseases	4%	2%	5%	4%	1%	1%	1%	2%	1%	1%	0%	0%	2%	1%	0%	1%	0%	1%	0%	0%	3079
Malignant neoplasms	6%	0%	4%	0%	1%	1%	1%	0%	0%	0%	0%	0%	2%	0%	0%	1%	1%	0%	0%	0%	2721
Resp. infections/diseases	6%	6%	4%	4%	2%	1%	2%	2%	2%	2%	1%	2%	1%	1%	0%	4%	1%	1%	0%	3%	2183
Diabetes mellitus	4%	2%	4%	1%	2%	1%	3%	1%	0%	0%	0%	1%	2%	1%	0%	1%	1%	0%	0%	1%	2150
Endocrine blood immune disorders	8%	5%	2%	2%	2%	2%	1%	0%	1%	1%	1%	2%	1%	1%	0%	0%	0%	0%	1%	1%	2144
Neurological conditions	6%	4%	4%	1%	2%	2%	2%	1%	0%	0%	0%	1%	1%	1%	0%	1%	2%	0%	0%	1%	2000
Genitourinary diseases	5%	1%	2%	1%	1%	1%	2%	1%	1%	0%	0%	1%	1%	0%	0%	0%	1%	0%	0%	1%	1967
Cardiovascular diseases	6%	2%	6%	0%	1%	2%	6%	1%	0%	0%	0%	1%	2%	0%	0%	1%	2%	0%	0%	2%	1814
Mental and substance use disorders	10%	3%	4%	1%	3%	3%	5%	2%	1%	0%	0%	1%	1%	1%	0%	3%	2%	1%	0%	4%	1733
Digestive disease	3%	1%	2%	1%	1%	1%	1%	2%	0%	0%	0%	0%	1%	0%	0%	1%	0%	0%	0%	0%	1490
Hepatitis	6%	2%	4%	1%	2%	1%	1%	0%	1%	0%	1%	1%	1%	0%	0%	1%	0%	0%	0%	0%	1296
Musculoskeletal disease	2%	2%	2%	1%	1%	1%	3%	1%	0%	0%	0%	1%	1%	0%	0%	1%	0%	0%	0%	3%	1088
Intestinal nematode	5%	7%	4%	3%	3%	1%	0%	2%	1%	1%	0%	2%	2%	1%	0%	1%	0%	0%	0%	0%	1017
Sense organ diseases	5%	4%	1%	1%	1%	0%	1%	1%	0%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	888
Skin diseases	2%	3%	3%	1%	2%	0%	0%	1%	1%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	837
Meningitis	14%	11%	6%	7%	3%	6%	3%	4%	3%	2%	2%	3%	1%	1%	1%	2%	1%	1%	1%	3%	599
Congenital anomalies	4%	1%	1%	1%	1%	0%	1%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	470
STDs exc HIV	21%	8%	2%	9%	2%	2%	1%	2%	5%	4%	2%	3%	1%	4%	3%	1%	1%	0%	4%	0%	424
Neonatal conditions	9%	4%	1%	10%	2%	1%	2%	4%	4%	1%	1%	1%	0%	1%	1%	0%	0%	0%	0%	0%	392
Maternal conditions	3%	3%	1%	6%	1%	0%	1%	7%	4%	0%	0%	1%	0%	4%	0%	0%	1%	0%	2%	0%	380
Childhood-cluster diseases	6%	5%	3%	7%	10%	3%	1%	10%	2%	10%	1%	3%	0%	2%	0%	1%	0%	1%	1%	1%	354
Nutritional deficiencies	8%	7%	1%	4%	3%	1%	2%	2%	5%	2%	0%	2%	1%	1%	0%	1%	1%	0%	0%	0%	347
Oral conditions	5%	3%	2%	0%	4%	1%	1%	2%	2%	0%	1%	1%	0%	2%	0%	0%	0%	1%	0%	0%	311
Encephalitis	6%	3%	5%	0%	3%	2%	0%	2%	1%	2%	0%	1%	0%	0%	0%	0%	0%	0%	1%	0%	86
Leprosy	5%	1%	3%	1%	3%	1%	1%	4%	0%	0%	3%	0%	0%	1%	0%	1%	0%	0%	0%	0%	78
Total	3317	1756	1404	1381	1034	735	722	710	701	499	460	450	402	376	374	328	324	305	303	302	

Note: Own calculation based on WoS.

burden and research specialisation is in Eastern Africa.

To assess the extent to which a higher share of funding from international donors in specific scientific areas/diseases is associated with a higher disease burden specialisation, we compute an additional set of regressions that have as dependant variables the normalised specialisation index of a certain funder type in a specific disease. As stated in the Data and Methods section, this study covers five types of funding organisations, i.e. Public African, public non-African (includes public non-African and multilateral), philanthropic, corporation and non-funded (or non-identified), and we used the full counting method (if a publication has two different types of funding institutions in their acknowledgements we counted one publication for each funding institution/disease). We run a regression for each dependant variable where the main independent variable is the disease burden specialisation (NSI_DALYs) of a certain disease in an African region, and we controlled for level of international collaboration and previous relative specialisation of a funder group.

Comparisons of results from the five sub-groups in Table 5 enable us to observe a set of findings: First, the disease fields in which public non-African and philanthropic organisations fund relatively more are the ones, on average, that have higher disease burden specialisation, in Eastern Africa, Southern Africa and Western & Central Africa. As we have seen in Fig. 4, these three regions are highly dependant on international research funding. Therefore, this finding is significant since it shows that these international donors, on average, are funding research on diseases that are relevant to these African regions. In Northern Africa, there is a negative association between disease burden specialisation and research funding specialisation in all funding

categories. These results mirror the results documented in Table 4 that shows that medical research in Northern Africa is not associated with their disease burden.

Second, Eastern Africa is the only region where exists a positive association, on average, between disease burden specialisation and public African funding specialisation. Third, publications funded by corporation funding seem to be positively associated on average with disease burden in all regions except for Northern Africa. Fourth, there is no clear association between unfunded research that is not funded by a specific institution and disease burden specialisation (see model 10 in Table 5). The only driver of research that has no funding acknowledgements seems to be the previous specialisation on that topic (lagged dependant variable).

Finally, we should note that we control for the level of international collaboration and previous share of research funding (2009–2010) for all the dependant variables. As expected, we only find a significant positive association between the intensity of international collaboration and medical research funded by public non-African/philanthropic organisations (see models 4 & 6 in Table 4). This may happen because in Africa, research done in international collaboration is usually supported by external research funding institutions. As for the previous funding specialisation in a specific disease, there is a positive association between our lagged variable and all dependant variables. This indicates research funding is in general path-dependant. Investing requires confidence on the part of the investor that they will see a return on their investment. In environments where the logistics for research might be complex and challenging, the inclination is to fund governments and institutions with a track record of success (Head et al., 2017).

Table 3
Share of research supported by each funder group in each African region by disease.
Source: Own calculation based on WoS and WHO.

	Public non-African						Public non-African						Public non-African						Public non-African					
	Philanthropic	Public African	Corporation	Total Pubs	DALYs		Philanthropic	Public African	Corporation	Total Pubs	DALYs		Philanthropic	Public African	Corporation	Total Pubs	DALYs		Philanthropic	Public African	Corporation	Total Pubs	DALYs	
	Eastern Africa						Northern Africa						Southern Africa						West and Central Africa					
Parasitic and vector diseases	44%	54%	38%	37%	39%	6%	19%	10%	5%	37%	9%	1%	12%	15%	11%	4%	11%	0%	57%	59%	34%	34%	40%	12%
HIV/AIDS	22%	18%	20%	20%	20%	14%	2%	1%	2%	2%	1%	0%	28%	17%	28%	19%	22%	41%	8%	5%	9%	8%	9%	6%
Tuberculosis	15%	10%	14%	14%	12%	3%	4%	3%	2%	5%	3%	1%	32%	17%	38%	14%	20%	4%	7%	6%	8%	4%	6%	3%
Diarrhoeal diseases	5%	5%	9%	6%	7%	9%	13%	16%	2%	5%	11%	3%	4%	10%	4%	5%	7%	3%	7%	7%	12%	6%	8%	10%
Malignant neoplasms	2%	1%	1%	3%	2%	4%	17%	16%	15%	13%	15%	7%	3%	7%	2%	3%	5%	5%	3%	3%	3%	3%	4%	2%
Resp. infections/diseases	5%	9%	5%	11%	6%	13%	6%	6%	11%	7%	6%	10%	5%	6%	6%	17%	7%	9%	5%	6%	4%	12%	6%	16%
Diabetes mellitus	2%	1%	3%	5%	3%	1%	7%	8%	23%	7%	9%	4%	4%	7%	3%	10%	6%	4%	2%	2%	7%	7%	6%	1%
Endocrine blood immune disorders	5%	5%	7%	8%	4%	1%	5%	7%	10%	5%	8%	2%	3%	3%	3%	7%	4%	1%	5%	4%	7%	3%	6%	2%
Neurological conditions	2%	4%	4%	4%	4%	2%	7%	7%	10%	7%	8%	4%	4%	6%	5%	4%	6%	2%	3%	3%	3%	3%	4%	1%
Genitourinary diseases	2%	1%	3%	2%	3%	1%	6%	5%	6%	6%	9%	3%	3%	3%	2%	4%	4%	1%	2%	1%	5%	2%	4%	1%
Cardiovascular diseases	2%	2%	3%	8%	3%	5%	5%	6%	16%	3%	6%	19%	6%	8%	5%	18%	8%	8%	2%	1%	4%	5%	3%	5%
Mental and substance use disorders	2%	2%	3%	4%	3%	3%	5%	3%	10%	7%	5%	7%	7%	7%	7%	14%	8%	4%	2%	4%	7%	11%	4%	2%
Digestive disease	1%	1%	1%	4%	2%	2%	4%	8%	5%	4%	8%	5%	1%	2%	1%	2%	3%	2%	2%	2%	3%	3%	3%	3%
Hepatitis	1%	1%	1%	3%	2%	0%	5%	8%	8%	4%	6%	0%	2%	3%	1%	2%	2%	0%	3%	1%	3%	4%	3%	0%
Musculoskeletal disease	0%	0%	1%	2%	1%	1%	3%	4%	10%	4%	6%	4%	2%	3%	1%	5%	2%	2%	1%	1%	1%	2%	1%	1%
Intestinal nematode	3%	4%	5%	3%	4%	0%	4%	5%	1%	4%	3%	0%	1%	2%	1%	1%	2%	0%	3%	2%	4%	2%	3%	0%
Sense organ diseases	1%	2%	1%	1%	1%	1%	3%	3%	3%	7%	4%	3%	1%	1%	1%	1%	2%	1%	1%	1%	2%	0%	2%	1%
Skin diseases	1%	1%	3%	1%	1%	1%	2%	2%	1%	2%	4%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%	2%	0%
Meningitis	2%	2%	1%	5%	2%	3%	1%	1%	0%	1%	1%	1%	2%	2%	3%	3%	2%	1%	2%	4%	2%	11%	2%	3%
Congenital anomalies	0%	0%	0%	0%	1%	3%	1%	1%	0%	1%	2%	4%	0%	0%	0%	0%	1%	2%	0%	0%	0%	0%	1%	3%
STDs exc HIV	3%	3%	1%	2%	2%	1%	1%	0%	0%	0%	1%	1%	2%	1%	1%	1%	1%	0%	1%	2%	0%	0%	1%	1%
Neonatal conditions	1%	2%	1%	2%	2%	15%	1%	0%	0%	0%	1%	13%	1%	1%	2%	0%	1%	5%	1%	2%	2%	0%	2%	16%
Maternal conditions	1%	1%	1%	1%	2%	2%	0%	0%	0%	0%	0%	1%	1%	1%	1%	0%	1%	0%	1%	2%	1%	0%	2%	2%
Childhood-cluster diseases	1%	1%	1%	1%	1%	3%	1%	0%	0%	0%	0%	1%	1%	1%	1%	1%	1%	1%	3%	2%	1%	12%	2%	2%
Nutritional deficiencies	1%	2%	3%	2%	2%	5%	1%	1%	0%	1%	1%	3%	1%	1%	1%	0%	1%	2%	1%	1%	1%	1%	1%	5%
Oral conditions	1%	0%	1%	0%	1%	0%	1%	1%	0%	1%	1%	1%	1%	1%	0%	0%	1%	0%	0%	0%	1%	0%	1%	0%
Encephalitis	0%	0%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Leprosy	0%	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Total in region	3598	2043	634	333	9061	74502	1530	206	1161	212	12020	23825	2471	1253	2405	684	8938	12657	2209	1097	507	273	8058	127801

Note: DALYs from 2010 and scientific publications from 2011–2015.

5. Discussion and conclusions

While the vast majority of the burden of disease globally is based in low and middle-income countries, only a small proportion of medical research is performed in those regions. Therefore a common rationale is that these countries should use their limited resources to study diseases that are relevant to their health needs.

In this article, we evaluate the alignment between the medical research effort and the burden of disease across four African regions. Within each region, we estimated the research and disease burden specialisation (compared to the world specialisation levels) across 28 diseases.

Our results show that, between 2006 and 2015, the world share of medical research done by African researchers accounted to only 2.1%, a marked contrast to the fact that almost 28% of the global disease burden is in the continent. However, despite their weak research capacity and strong dependency on international research collaborations, we find that in sub-Saharan Africa most medical research has been conducted on diseases that are relevant to the region. In other words, most diseases with high disease burden are also the ones with relatively more research effort. We find that the region with the highest positive association between disease burden and research effort specialisation is Eastern Africa. Northern Africa is the region where these two dimensions are less aligned in relative terms.

These findings are interesting for two main reasons. First, it has

been argued that there are substantial misalignments, at the global level, between research efforts and WHO estimates of health burden for a given disease (e.g. Evans et al., 2014; Rafols and Yegros, 2017). While this may be true at the global level in absolute terms (high-income countries perform most of their medical research on diseases that are not the ones with a higher global disease burden), sub-Saharan African researchers are performing research in diseases in accordance with their regional health needs. Second, there are some concerns about to what extent high levels of international research funding and collaboration in lower-income contexts are associated to a lack of alignment between research priorities and local health needs. Our results show that a heavy reliance on international funding and collaboration does not necessary lead to a compromise in research priorities. At least in the context of medical research in Africa, there is no clear trade-off between participating in global research networks and producing medical research that is aligned with local health needs. As a consequence, establishing funding partnerships and other collaborative solutions between countries have the potential to generate relevant medical research for countries with few resources.

The fact that international medical research funders' priorities seem to be aligned with local African health needs does not necessarily mean that African countries do not need stronger scientific and institutional capacity. It is well known that substantial advantages exist in investment in local research, particularly with regard to ownership of the results, trust, inter-sector sharing of expertise between researchers and

Table 4
Regression analysis: Match between disease burden specialisation and research specialisation.

Ind. Variables	NSI_Pubs_11.15				
	model (1)	model (2)	model (3)	model (4)	model (5)
NSI_DALYs_2010	0.76*** (0.10)				
NSI_DALYs_2010*Eastern_Africa		1.21*** (0.14)	1.20*** (0.14)	1.08*** (0.15)	0.11** (0.046)
NSI_DALYs_2010*Northern_Africa		-0.016 (0.29)	-0.047 (0.28)	-0.37 (0.29)	-0.042 (0.053)
NSI_DALYs_2010*Southern_Africa		0.46* (0.25)	0.53** (0.27)	0.56*** (0.21)	0.065* (0.039)
NSI_DALYs_2010*West&Central_Africa		0.90*** (0.11)	0.91*** (0.11)	0.71*** (0.14)	0.048 (0.055)
Int_collab_11_15 (%)				1.14*** (0.30)	0.16** (0.081)
L_NSI_Pubs					0.89*** (0.022)
Constant	0.076** (0.031)	0.058* (0.029)	0.029 (0.062)	-0.90*** (0.26)	-0.078 (0.064)
Regional dummies	No	No	Yes	Yes	Yes
Observations	103	103	103	103	103
R-squared	0.393	0.510	0.516	0.571	0.967

Note 1: Robust standard errors in parentheses;

Note 2: In estimations 3–5, the regression model is computed controlling for four regions: Eastern Africa, Northern African, Southern Africa and West & Central Africa.

*** $p < 0.01$,

** $p < 0.05$,

* $p < 0.1$.

Table 5
Regression analysis: Match between disease burden specialisation of a region and medical research specialisation of a specific funder group.

Ind. Variables	Research specialisation of African funders		Research specialisation of non-African public funders		Research specialisation of philanthropic funders		Research specialisation of corporation funders		Unfunded.research	
	model (1)	model (2)	model (3)	model (4)	model (5)	model (6)	model (7)	model (8)	model (9)	model (10)
NSI_DALYs_2010*	1.06*** (0.16)	0.57** (0.22)	1.26*** (0.17)	0.33*** (0.089)	1.40*** (0.13)	0.70** (0.15)	1.16*** (0.15)	0.79*** (0.15)	0.86*** (0.16)	-0.056 (0.081)
Eastern_Africa										
NSI_DALYs_2010*	-0.44 (0.41)	-0.39 (0.27)	-0.50* (0.29)	-0.36*** (0.12)	-0.65** (0.32)	-0.68** (0.29)	-0.084 (0.29)	-0.49 (0.30)	0.17 (0.26)	0.071 (0.11)
Northern_Africa										
NSI_DALYs_2010*	0.51* (0.29)	0.29* (0.15)	0.51 (0.35)	0.19** (0.073)	0.66** (0.32)	0.47*** (0.17)	0.60** (0.24)	0.42*** (0.095)	0.58** (0.26)	0.055 (0.055)
Southern_Africa										
NSI_DALYs_2010*	0.74*** (0.18)	0.26 (0.18)	1.14*** (0.11)	0.17* (0.097)	1.25*** (0.11)	0.56*** (0.13)	0.86*** (0.17)	0.35** (0.17)	0.73*** (0.13)	-0.021 (0.084)
West&Central_Africa										
Int_collab_11_15 (%)		0.32 (0.37)		0.44** (0.18)		0.90*** (0.32)		0.91* (0.48)		0.24* (0.14)
African_Funding										
L_NSI_FUNDCAT		0.47*** (0.091)								
Non-African_Funding				0.72*** (0.053)						
L_NSI_FUNDCAT										
Philanthropic_Funding						0.41*** (0.083)				
L_NSI_FUNDCAT										
Corporation_Funding								0.38*** (0.066)		
L_NSI_FUNDCAT										0.86*** (0.049)
Unfunded										
L_NSI_FUNDCAT										
Constant	-0.015 (0.077)	-0.18 (0.31)	-0.035 (0.072)	-0.34** (0.15)	-0.026 (0.067)	-0.70*** (0.27)	0.029 (0.076)	-0.58 (0.40)	-0.41*** (0.060)	-0.36*** (0.12)
Regional effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	101	101	101	101	101	101	101	101	101	101
R-squared	0.367	0.584	0.503	0.899	0.544	0.728	0.375	0.624	0.651	0.934

Note 1: Robust standard errors in parentheses;

Note 2: The regression model is computed controlling for four regions: Eastern Africa, Northern African, Southern Africa and West & Central Africa.

*** $p < 0.01$,

** $p < 0.05$,

* $p < 0.1$.

policymakers, and increased contextualisation of findings. Besides that, one important gap in international health research funding is its focus on biomedical sciences, with less emphasis on applied and health systems research (AMS-IAP, 2017; Cochrane et al., 2017). This is problematic because, without health systems research, the ability of health practitioners and local policymakers to use research results may be seriously constrained. Therefore, creating schools of public health and other institutions to train quality scientists in public health should continue to be a priority, as many African countries have few or no institutions that can provide proper training in public health research.

Our study has limitations, and the results must be interpreted with caution since publications in WoS (or DALYs) are imperfect estimates of research efforts (health needs) in a specific disease and country. First, this study focuses on one type of solution (i.e. scientific research) to cure or prevent diseases. Our central assumption is that a misalignment between research priorities and disease burden may reduce the impact of the investments in research to address health challenges. However, the efficiency of different types of solutions, including scientific research, improving the social environment, reducing lifestyle risks, etc., are not examined in this research. Second, measurement of priorities in medical research with scientific publications associated to certain diseases is not straightforward because there is some medical research related to health education approaches, beliefs related to health and prevention, quality and financing of healthcare, that is important for health outcomes and do not necessarily derive from research on certain diseases (Chavarro et al., 2017). Third, there is a language bias in WoS as English journals are preferred to the detriment of other languages (Mongeon and Paul-Hus, 2016).

As for future research, since scientific production and disease burden change over time, upcoming studies should conduct a dynamic analysis of DALYs and publications to understand how the two dimensions evolve together. Future studies should also analyse the extent to which the research that is funded is actually used to contribute to health action. Finally, it would be extremely interesting to use mobility

data to go one step beyond and study the science policy trade-offs between global integration of African scholars in high-income countries universities, and health and infrastructural concerns of their developing home countries.

CRedit authorship contribution statement

Hugo Confraria: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Lili Wang:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - review & editing, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are particularly grateful to Robin Cowan, Bart Verspagen, Tommaso Ciarli, Ismael Ràfols, Joanna Chataway, Michael Hopkins and Daniele Rotolo for their useful comments and suggestions. We also thank Rodrigo Costas and CWTS for providing valuable funding data, and Charlotte Oliveira and Marco Salvador for reviewing our keywords queries for each disease. This article also benefited from comments made by participants of a SPRU workshop (Brighton, 2018), UNU-MERIT internal conference (Maastricht, 2018), ISSI2019 (Rome) and ATLC 2019 (Atlanta). This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors. Any remaining error is ours.

Appendix

Table A.2, Table A.3

Table A.1
Keywords queries for each disease.

Diseases	Query
1 - Communicable, maternal, perinatal and nutritional conditions	
1.1 - Infectious and parasitic diseases	
1.1.1 - Tuberculosis	"tuberculosis" OR "tubercolosis" OR "tubercle bacillus" OR "tuberculin" OR "tb infection" OR "pulmonary tb" OR "extrapulmonary tb"
1.1.2 - STDs excluding HIV	"Syphilis" OR "Chlamydia" OR "Gonorrhoea" OR "Trichomoniasis" OR "Genital herpes"
1.1.3 - HIV/AIDS	("hiv/aids" OR "human immunodeficiency virus" OR "human immuno-deficiency virus" OR "acquired immunodeficiency syndrome" OR "acquired immuno-deficiency syndrome" OR "hiv infection") NOT (feline OR simian)
1.1.4 - Diarrhoeal diseases	"Diarrhoeal" OR "diarrhoea" OR "E. coli" OR "E. Coli" OR "V. cholerae" OR "shigellosis" OR "shigella" OR "Giardia" OR "cryptosporidium" OR "rotavirus"
1.1.5 - Childhood-cluster diseases	"Whooping cough" OR "pertussis" OR "Diphtheria" OR "diphtheriae" OR "Measles" OR "rubeola" OR "neonatal tetanus" OR "tetanus neonatal" OR "mumps virus" OR "Poliomyelitis"
1.1.6 - Meningitis	"Meningitis" OR "meningitidis" OR "neisseria pneumoniae" OR "cryptococ*" OR "meningococcus"
1.1.7 - Encephalitis	"Encephalitis"
1.1.8 - Hepatitis	"Hepatitis"
1.1.9 - Parasitic and vector diseases	("Malaria" OR "plasmodium" OR "anopheles" OR "black water fever") NOT "physarum") OR "Human african trypanosomiasis" OR "sleeping sickness" OR "trypanosom human" OR "Chagas disease" OR "American Trypanosomiasis" OR "Trypanosoma cruzi" OR "Trypanosoma brucei" OR "Schistosomiasis" OR "bilharzia" OR "Schistosoma mansoni" OR "Schistosoma haematobium" OR "Schistosoma intercalatum" OR "Schistosoma japonicum" OR "Schistosoma mekongi" OR "Leishmaniasis" OR "Leishmania" OR "phlebotomine" OR "psychodidae" OR "kalaazar" OR "kala-azar" OR "kala azar" OR "sand fly" OR "sandflies" OR "sand flies" OR "filariasis" OR "elephantiasis" OR "wuchereria" OR "brugia malayi" OR "Onchocerciasis" OR "Onchoceriiasis" OR "river blindness" OR "onchocerca volvulus" OR "Cysticercosis" OR "taeniasis" OR "Taenia solium" OR "Echinococcosis" OR "hydatid disease" OR "echinococcus" OR "dengue" OR "aedes aegypti" OR "aedes albopictus" OR "Trachoma" OR "chlamydia trachomatis" OR "Yellow fever" OR "Rabies" OR "zika virus" OR "Flavivirus" OR "chikungunya" OR "Lassa fever" OR "Ebola" OR "Haemorrhagic Fever" OR "typhoid" OR "loiasis" OR "cestodes"

(continued on next page)

Table A.1 (continued)

Diseases	Query
1.1.10 - Intestinal nematode infections	("fasciolosis" OR "fascioliasis" OR "distomatosis" OR "fasciola hepatica" OR "fasciola gigantica" OR "distomatosis") NOT "cattle" OR "dracunculiasis disease" OR "guinea-worm disease" OR "guinea worm disease" OR "dracunculus medinensis" OR "salmonella" OR "paratyphoid fever" OR "ancylostomiasis" OR "strongyloidiasis" OR "Ascariasis" OR "Trichuriasis" OR "Hookworm*" OR "heminth*" OR "hook-worm*" OR "hook worm*" OR "ascaris lumbricoides" OR "trichuris trichiura" OR "geohelminth*" OR "necatoramericanus" OR "necator americanus" OR "necatoriasis" OR "ancylostoma duodenale" OR "ancylostoma-duodenale" OR "clonorchiasis" OR "opisthorchiasis" OR "paragonimiasis"
1.1.11 - Leprosy	"Leprosy" OR "hansen disease" OR "mycobacterium leprae"
1.2 - Respiratory infections & diseases	"respiratory infectio*" OR "Asbestosis" OR "rheumatic fever" OR "Haemophilus Influenzae" OR "lung absces" OR "bronchitis" OR "Streptococcus pneumoniae" OR "pneumonia" OR "Moraxella catarrhalis" OR "Klebsiella pneumonia" OR "tonsillitis" OR "rhinitis" OR "sinus infection" OR "sinusitis" OR "rhinosinusitis" OR "rhinopharyngitis" OR "nasopharyngitis" OR "pharynx inflammation" OR "hypopharynx inflammation" OR "uvula inflammation" OR "tonsils inflammation" OR "pharyngitis" OR "epiglottitis" OR "laryngitis" OR "laryngotracheitis" OR "tracheitis" OR "Otitis media" OR "Respiratory diseases*" OR "Chronic obstructive pulmonary disease" OR "Asthma" OR "emphysema" OR "Laryngotracheitis" OR "Epiglottitis" OR "Bacterial tracheitis"
1.3 - Maternal conditions	"maternal death" OR "maternal mortality" OR "pregnancy infection*" OR "abortion care" OR "unsafe abortion" OR "childbirth severe bleeding" OR "childbirth infection*" OR "Placental abruptio*" OR "placenta praevia"
1.4 - Neonatal conditions	"Preterm birth" OR "Birth asphyxia" OR "birth trauma" OR "Neonatal sepsis" OR "neonatal infection*" OR "Gastroschisis" OR "Jaundice" OR "Necrotizing enterocolitis" OR "Persistent pulmonary hypertension of the newborn" OR "Intrauterine growth restriction" OR "Bronchopulmonary dysplasia" OR "infant apnoea" OR "infant respiratory distress syndrome" OR "asphyxia at birth" OR "anaemia in neonates" OR "neonatal alloimmune thrombocytopenia" OR "bronchopulmonary dysplasia" OR "cardiac failure in neonates" OR "hyaline membrane disease" OR "hypocalcaemia in neonates" OR "hypoglycaemia of the newborn" OR "hyponatraemia in neonates" OR "hypothermia in neonates" OR "intestinal obstruction in neonates" OR "pulmonary interstitial emphysema"
1.5 - Nutritional deficiencies	"Nutritional deficienc*" OR "Protein energy malnutrition" OR "Protein-energy malnutrition" OR "Iodine deficiency" OR "Iron-deficiency anaemia" OR "Nutritional deficienc*" OR "Thiamine deficiency" OR "vitamin B-1 deficiency" OR "Niacin deficiency" OR "vitamin B-3 deficiency" OR "vitamin B-9 deficiency" OR "Folate deficiency" OR "Cobalamin deficiency" OR "vitamin B-12 deficiency" OR "Vitamin D deficiency" OR "Calcium deficiency" OR "marasmus" OR "Kwashiorkor" OR "Marasmic-kwashiorkor" OR "nutritional oedema" OR "severe acute malnutrition" OR "moderate acute malnutrition" OR "Vitamin A deficiency"
2 - Noncommunicable diseases	
2.1 - Malignant neoplasms	"malignant neoplasm*" OR "Mouth cancer" OR "oropharynx cancer" OR "Lip cavity" OR "oral cavity" OR "Nasopharynx" OR "Oesophagus cancer" OR "Stomach cancer" OR "Colon cancer" OR "rectum cancer" OR "Liver cancer" OR "Pancreas cancer" OR "Trachea cancer" OR "bronchus cancer" OR "lung cancer" OR "Melanoma" OR "skin cancer" OR "Breast cancer" OR "Cervix uteri cancer" OR "Corpus uteri cancer" OR "Ovary cancer" OR "Prostate cancer" OR "Testicular cancer" OR "Kidney cancer" OR "Bladder cancer" OR "Brain cancer" OR "nervous system cancer" OR "Gallbladder cancer" OR "biliary tract cancer" OR "Larynx cancer" OR "Thyroid cancer" OR "Mesothelioma" OR "Lymphoma*" OR "multiple myeloma" OR "Leukaemia"
2.2 - Diabetes mellitus	diabete*
2.3 - Endocrine, blood, immune disorders	"Endocrine disorder*" OR "blood disorder*" OR "immune disorder*" OR "Glucocorticoid deficiency" OR "Glucose intolerance" OR "goitre" OR "Hyperparathyroidism" OR "Hyperthyroidism" OR "Hypoglycemia" OR "Hypoparathyroidism" OR "Hypothyroidism" OR "Mineralocorticoid deficiency" OR "Pseudohypoparathyroidism" OR "Thyroid cyst" OR "Thyroid nodule" OR "Thyroiditis" OR "Acidosis" OR "Alkalosis" OR "Amyloidosis" OR "Thalassaemias" OR "Sickle cell disorder" OR "trait disorder" OR "haemoglobinopathies" OR "haemolytic anaemia" OR "Cystic fibrosis" OR "Dysmetabolic syndrome" OR "Hemochromatosis" OR "Hyperbilirubinemia" OR "Hypercalcemia" OR "hypercholesterolaemia" OR "Hyperkalemia" OR "hyperlipidaemia" OR "Hypernatremia" OR "Hypertriglyceridemia" OR "Hypocalcemia" OR "Hypokalemia" OR "Hyponatremia" OR "Hypovolemia" OR "Magnesium disorder*" OR "Obesity hypoventilation syndrome" OR "Porphyria" OR "Renal osteodystrophy" OR "anaemia" OR "Coagulation defects" OR "Eosinophilia" OR "haemophilia" OR "Hypercoagulable state" OR "Idiopathic thrombocytopenic purpura" OR "Leukocytopenia" OR "Leukocytosis" OR "Lymphadenitis" OR "Neutropenia" OR "Polycythemia vera" OR "Sickle cell" OR "Thrombocytopenia"
2.4 - Mental and substance use disorders	"mental disorder*" OR "substance disorder*" OR "behavioural disorder*" OR "Agoraphobia" OR "Anorexia nervosa" OR "Antisocial personality disorder" OR "Anxiety state" OR "Attention deficit" OR "hyperactivity" OR "Bipolar disorder" OR "Borderline personality disorder" OR "Bruxism" OR "Bulimia nervosa" OR "Conduct disorder" OR "Conversion disorder" OR "Delirium tremens" OR "Dementia" OR "Depression disorder" OR "Depressive disorder" OR "Depressive psychosis" OR "Dyspareunia" OR "Encopresis" OR "Enuresis" OR "Explosive personality disorder" OR "Fluency disorder" OR "Generalized anxiety disorder" OR "Hysteria disorder" OR "Hysterical psychosis" OR "Insomnia" OR "sleep disorder" OR "Intellectual disability*" OR "Neurosis" OR "Neurotic depression" OR "Obsessive-compulsive disorder" OR "Panic disorder" OR "Paranoid reaction" OR "Personality disorder" OR "Post-traumatic stress disorder" OR "Premature ejaculation" OR "Psychosis" OR "Schizoaffective" OR "Schizophrenia" OR "Sleep disorder" OR "Somatization disorder" OR "Somnambulism" OR "Suicidal ideation" OR "Alcohol abuse" OR "Alcoholism" OR "Amphetamine dependence" OR "Cannabis abuse" OR "Cannabis dependence" OR "Cocaine abuse" OR "Cocaine dependence" OR "Drug abuse" OR "Drug withdrawal" OR "Drug-induced paranoia" OR "Opioid abuse" OR "Opioid dependence" OR "Tobacco abuse" OR "dysthymia" OR "opioid disorder" OR "cocaine disorder" OR "amphetamine disorder" OR "cannabis disorder" OR "panic attack" OR "Social anxiety disorder" OR "separation anxiety disorder" OR "selective mutism" OR "eating disorder" OR "Anorexia Nervosa" OR "Bulimia Nervosa" OR "Binge Eating Disorder" OR "Muscle dysmorphia" OR "autism" OR "asperger syndrome" OR "autistic" OR "Attention deficit" OR "hyperactiv* syndrome" OR "Conduct disorder" OR "Idiopathic intellectual disability" OR "mental retardation" OR "Bell's palsy" OR "Blepharospasm" OR "Carpal tunnel" OR "Cerebral aneurysm" OR "Cerebral artery occlusion" OR "Cerebral oedema" OR "Cerebral palsy" OR "Cognitive impairment" OR "Encephalopathy" OR "Epilepsy" OR "Guillain-Barré" OR "Hemiplegia" OR "Hydrocephalus" OR "Migraine" OR "Morton's neuroma" OR "Multiple sclerosis" OR "Myasthenia gravis" OR "Narcolepsy" OR "Neuralgia" OR "Neuropathy" OR "Parkinsonism" OR "Phantom limb" OR "Post-concussion syndrome" OR "Postherpetic neuralgia" OR "Pseudotumor cerebri" OR "Reflex sympathetic" OR "Restless legs syndrome" OR "Reye's syndrome" OR "Sciatica" OR "Subarachnoid haemorrhage" OR "Subdural haemorrhage" OR "Thoracic outlet syndrome" OR "Tic disorder" OR "Tourette's disorder" OR "Trigeminal neuralgia" OR "Alzheimer*" OR "dementia" OR "chronic neurodegenerative" OR "Neurodegeneration" OR "Parkinson disease" OR "parkinsonian syndrome" OR "epileptic" OR "motor neuron disease" OR "huntington's disease"
2.5 - Neurological conditions	

(continued on next page)

Table A.1 (continued)

Diseases	Query
2.6 - Sense organ diseases	"otitic barotrauma" OR "Cerumen impaction" OR "Eustachian tube dysfunction" OR "Hearing loss" OR "viral Labyrinthitis" OR "Ménière's disease" OR "Nystagmus" OR "Otaglia" OR "Otitis externa" OR "Otitis media" OR "Presbycusis" OR "Tinnitus" OR "Vertigo" OR "Anisocoria" OR "Blepharitis" OR "eye cataract*" OR "Chalazion" OR "Conjunctivitis" OR "Corneal abrasion" OR "Corneal oedema" OR "Corneal ulcer" OR "Diplopia" OR "Dry eye syndrome" OR "Esotropia" OR "Glaucoma" OR "Hyphema" OR "Iritis" OR "cyclitis" OR "Lid lag" OR "Macular degeneration" OR "Papilledema" OR "Pterygium" OR "Retinal detachment" OR "Retinopathy" OR "Scotoma" OR "hordeolum" OR "Subconjunctival haemorrhage" OR "Visual disturbance" OR "Visual field defect" OR "Visual loss" OR "Uncorrected refractive errors" OR "sense organ disorder*" OR "cholesteatoma"
2.7 - Cardiovascular diseases	"Cardiovascular disease*" OR "Atrial fibrillation" OR "Atrial flutter" OR "Atrioventricular block" OR "Bundle branch block" OR "Long QT syndrome" OR "Sick sinus syndrome" OR "Sinoatrial heart block" OR "Sinus bradycardia" OR "paroxysmal tachycardia" OR "Angina pectoris" OR "artery bypass graft" OR "autologous vein bypass graft" OR "native coronary artery" OR "Cardiac arrest" OR "Cardiac contusion" OR "Cardiomyopathy" OR "Chronic ischaemic heart disease" OR "Endocarditis" OR "Heart failure" OR "Heart valve" OR "Kawasaki disease" OR "Myocarditis" OR "Pericarditis" OR "Prinzmetal angina" OR "Pulmonary heart disease" OR "Rheumatic heart disease" OR "Aortic aneurysm" OR "Aortic dissection" OR "Carotid sinus syndrome" OR "Deep vein thrombosis" OR "oesophageal varices" OR "heart hypertension" OR "Hypertensive heart" OR "Hypotension" OR "Intermittent claudication" OR "Peripheral vascular disease" OR "Phlebitis" OR "Polyarteritis nodosa" OR "Postmastectomy lymphedema" OR "Raynaud's syndrome" OR "Thrombophlebitis" OR "Transient ischaemic attack" OR "Varicose veins" OR "Venous embolism" OR "Venous insufficiency" OR "Wegener's granulomatosis" OR "Ischaemic heart disease" OR "Ischaemic stroke" OR "Haemorrhagic stroke" OR "myocardial infarction"
2.8 - Digestive diseases	"Digestive disease*" OR "Achalasia" OR "cardiospasm" OR "Anal spasm" OR "Angiodysplasia" OR "Aphthous ulcer" OR "Appendicitis" OR "Barrett's esophagitis" OR "Cholangitis" OR "Cholecystitis" OR "Cholelithiasis" OR "Cirrhosis" OR "Crohn's disease" OR "Diverticulitis of colon" OR "Duodenal ulcer" OR "Dyspepsia" OR "Edentulism" OR "oesophageal stricture" OR "oesophageal stenosis" OR "Esophagitis" OR "Fatty liver" OR "Gallbladder disease" OR "Gastric ulcer" OR "Gastritis" OR "Gastroenteritis" OR "Gastroesophageal reflux" OR "Gastroparesis" OR "Glossitis" OR "Hemorrhoids" OR "Impaction of intestine" OR "colostomy" OR "enterostomy" OR "Irritable bowel syndrome" OR "ischaemic bowel disease" OR "Leukoplakia" OR "Liver disease" OR "Mechanical complication of ostomy" OR "Pancreatitis" OR "Parotitis" OR "Peptic ulcer" OR "Periodontitis" OR "Ulcerative colitis" OR "duodenitis" OR "Paralytic ileus" OR "intestinal obstruction" OR "Inflammatory bowel disease"
2.9 - Genitourinary diseases	"Genitourinary" OR "Breast lump" OR "Fibroadenosis" OR "Fibrocystic disease" OR "Galactorrhoea" OR "gynaecomastia" OR "Mastitis" OR "Mastodynia" OR "amenorrhoea" OR "Menopausa*" OR "Metrorrhagia" OR "Mittelschmerz" OR "Premenstrual tension syndrome" OR "postmenopausal atrophic" OR "vulvo atrophy" OR "vaginal atrophy" OR "Bartholin abscess" OR "Bartholin cyst" OR "Cervical polyp" OR "Cervicitis" OR "Corpus luteum cyst" OR "Cyst of ovary" OR "Cystocele" AND "midline" OR "Dyspareunia" OR "Endometrial hyperplasia" OR "Endometriosis" OR "Fibroid uterus" OR "leiomyoma" OR "Leukorrhoea" OR "Ovarian failure" OR "Pelvic inflammatory disease" OR "uterine prolapse" OR "Rectocele" OR "Urethrocele" OR "Uterus hypertrophy" OR "Vaginismus" OR "Vaginitis" OR "vulvitis" OR "Vulvodynia" OR "Atrophy of testis" OR "Balanitis" OR "BPH/LUTS" OR "Hematospermia" OR "Hydrocele" OR "Orchitis" OR "epididymitis" OR "Phimosis" OR "Priapism" OR "Prostatitis" OR "Spermatocoele" OR "Testicular hypofunction" OR "Torsion of testis" OR "nongonococcal Urethritis" OR "Varicocele" OR "Atony of bladder" OR "Bladder hypertonicity" OR "Bladder neck obstruction" OR "kidney Calculus" OR "ureter Calculus" OR "urinary Calculus" OR "Cystitis" OR "Glomerulonephritis" OR "haematuria" OR "Hydronephrosis" OR "Kidney disease" OR "Nephrotic syndrome" OR "Proteinuria" OR "Pyelonephritis" OR "Renal failure" OR "urethral stricture" OR "Urethral syndrome" OR "Urinary obstruction" OR "Urinary tract infection" OR "Vesicoureteral" OR "prostatic hyperplasia" OR "Urolithiasis" OR "gynaecologic* disease" OR "infertility"
2.10 - Skin diseases	"skin disease*" OR "Acne" OR "Actinic keratosis" OR "Alopecia" OR "Cellulitis" OR "Contact dermatitis" OR "Cradle cap" OR "Dermatitis" OR "Dermatophytosis" OR "Diaper rash" OR "Eczema" OR "Erythema multiforme" OR "Erythema nodosum" OR "Hidradenitis suppurativa" OR "Hirsutism" OR "Impetigo" OR "Ingrown nail" OR "Keloid scar" OR "Lichen planus" OR "Lymphadenitis" OR "Onychomycosis" OR "Paronychia" OR "Pityriasis rosea" OR "Pressure ulcer" OR "Pruritus" OR "Psoriasis" OR "Sebacous cyst" OR "seborrhoeic dermatitis" OR "seborrhoeic keratosis" OR "Solar radiation dermatitis" OR "Stevens-Johnson syndrome" OR "Tinea cruris" OR "Tinea pedis" OR "Tinea versicolor" OR "Urticaria" OR "Vitiligo"
2.11 - Musculoskeletal diseases	"Musculoskeletal disease" OR "Musculoskeletal disorder" OR "Musculoskeletal pain" OR "Arthropathy" OR "Dermatomyositis" OR "Eosinophilia myalgia syndrome" OR "Fibromyalgia" OR "Myositis ossificans" OR "Osteoarthritis" OR "Osteochondritis" OR "Osteomyelitis" OR "Osteoporosis" OR "Polymyalgia rheumatica" OR "Polymyositis" OR "Rhabdomyolysis" OR "Sjögren's disease" OR "Synovitis" OR "tenosynovitis" OR "Systemic lupus erythematosus" OR "Temporomandibular arthralgia" OR "Aseptic necrosis" OR "Baker's cyst" OR "Bunion" OR "Calcaneal spur" OR "Chondromalacia of patella" OR "knee* derangement" OR "Hallux rigidus" OR "Hallux valgus" OR "Hammer toe" OR "Iliotibial band syndrome" OR "Knee effusion" OR "Metatarsalgia" OR "Pes anserinus tendinitis" OR "Plantar fasciitis" OR "Prepatellar bursitis" OR "Tendinitis" OR "Tenosynovitis" OR "Ankylosing spondylitis" OR "Cervical spondylosis" OR "Coccygodynia" OR "Costochondritis" OR "Degenerative disc disease" OR "Diastasis recti" OR "Kyphosis" OR "Lumbosacral spondylosis" OR "Postlaminectomy syndrome" OR "Sacroiliitis" OR "Scoliosis" OR "Somatic dysfunction" OR "Spinal stenosis" OR "Spondylolisthesis" OR "Thoracic spondylosis" OR "Torticollis" OR "Adhesive capsulitis" OR "Bicipital tenosynovitis" OR "Boutonniere deformity" OR "de Quervain's disease" OR "Dupuytren's contracture" OR "Lateral epicondylitis" OR "Mallet finger" OR "Medial epicondylitis" OR "Olecranon bursitis" OR "Swan-neck deformity" OR "Tenosynovitis" OR "Rheumatoid arthritis" OR "Osteoarthritis" OR "Gout" OR "Back pain" OR "neck pain" OR "Osteomyelitis"
2.12 - Congenital anomalies	"Arteriovenous malformation" OR "Atrial septal defect" OR "Hirschsprung's disease" OR "Hydrocephalus" OR "Hypospadias" OR "Imperforate anus" OR "Imperforate hymen" OR "Limb anomaly" OR "Marfan syndrome" OR "Meckel's diverticulum" OR "Microcephalus" OR "Osteogenesis imperfecta" OR "Pectus excavatum" OR "Pyloric stenosis" OR "Spina bifida" OR "Talipes equinovarus" OR "Tongue tie" OR "Congenital Muscular Torticollis" OR "Congenital Torticollis" OR "Undescended testis" OR "Ventricular septal defect" OR "Neural tube defects" OR "Cleft lip" OR "cleft palate" OR "Down syndrome" OR "trisomy" OR "Down's syndrome" OR "Congenital heart anomaly*" OR "Congenital anomaly*"
2.13 - Oral conditions	"Oral disorder" OR "oral disease" OR "mouth disease" OR "oral cancer" OR "Gingivitis" OR "Thrush" OR "Mouth Ulcer" OR "dental carie*" OR "periodontal disease" OR "edentulism" OR "tooth decay"

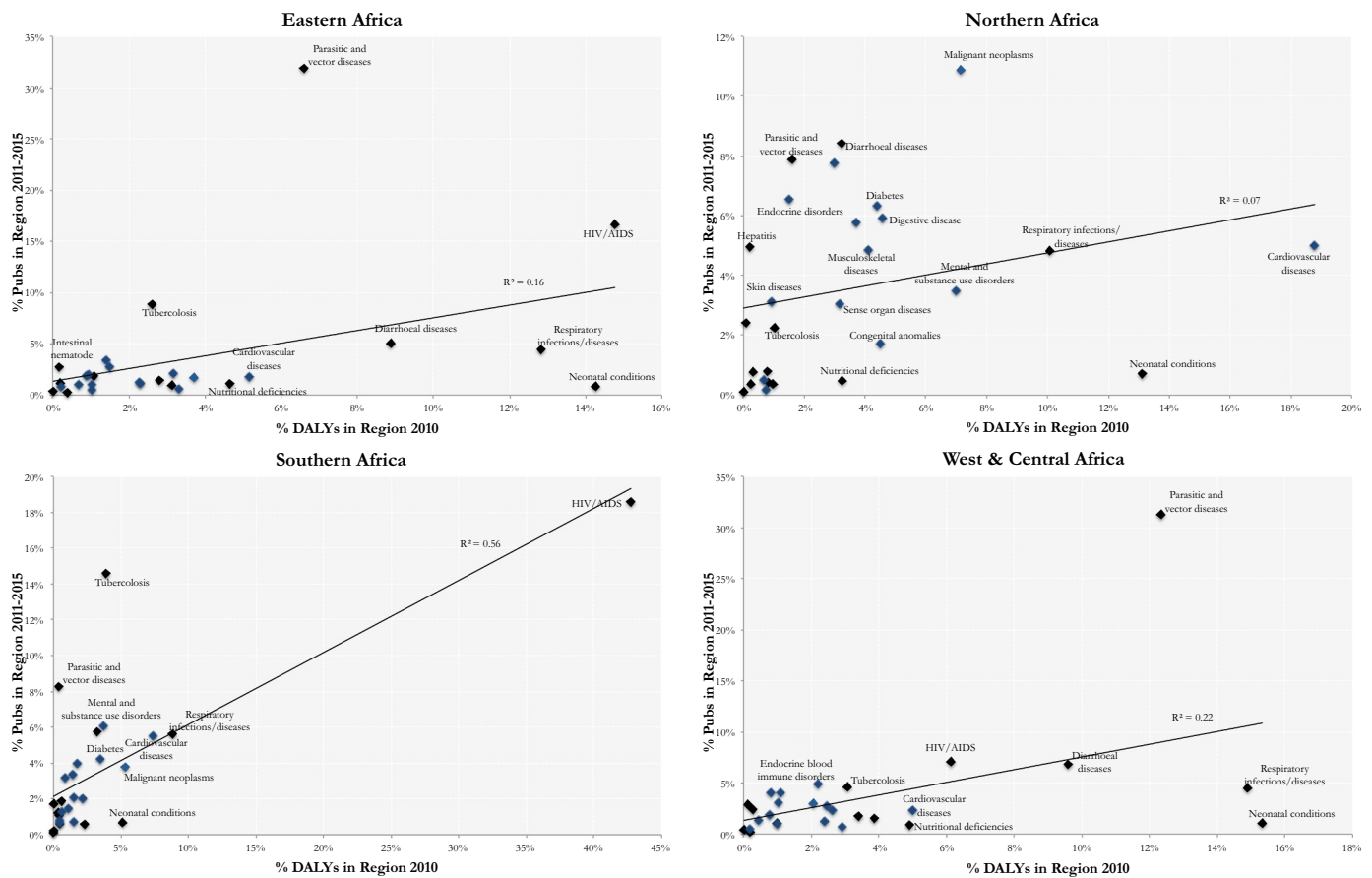


Fig. A.1. Disease burden share (%) vs research share (%) by disease.

Note 1: DALYs from 2010 and scientific publications from 2011–2015.

Note 2: Black dots show Group I diseases (communicable, maternal, perinatal and nutritional conditions). Blue dots show Group II diseases (non-communicable).

Source: Own calculation based on WoS and WHO.

Table A.2

Top 5 funding institutions by African region.

Region	Pubs diseases.% funded pubs	Top 5 funders (Num pubs) 2011–2015				
		1	2	3	4	5
Northern Africa	12,020	Tunisian_Gov	NIH_US	King_Saud_University	Egyptian_Gov	EU-EC-ERC
	37%	402	302	288	221	180
Southern Africa	8938	NRF_ZA	NIH_US	MRC_ZA	Wellcome_Trust	Gates_Foundation
	68%	1389	1163	722	623	329
Eastern Africa	9061	NIH_US	Wellcome_Trust	Gates_Foundation	USAID	EU-EC-ERC
	79%	1496	1053	827	359	331
West and Central Africa	8058	NIH_US	Gates_Foundation	Wellcome_Trust	EU-EC-ERC	WHO
	59%	684	481	380	368	322

Table A.3

Top 5 funding institutions by funding group.

Funding groups	Pubs diseases% pubs	Top 5 funders (Num pubs) 2011–2015				
		1	2	3	4	5
Public non-African	9922	NIH_US	EU-EC-ERC	WHO	USAID	CDC_US
	28%	3317	1034	710	701	180
Public African	4406	NRF_ZA	MRC_ZA	Tunisian_Gov	DST_ZA	Egyptian_Gov
	12%	1404	722	402	305	223
Philanthropic	4003	Wellcome Trust	Gates Foundation	Doris Duke Foundation	Howard Hughes Health Institute	Institut Pasteur
	11%	1756	1381	146	117	112
Corporation	1306	GlaxoSmithKline	Pfizer	Novartis	Merck	Sanofi Aventis
	4%	328	302	238	206	198

Table A.4
Disease burden (log) versus research output (log).

Ind. Variables	log_Pubs_11.15				
	model (1)	model (2)	model (3)	model (4)	model (5)
log_DALYs_2010	0.17*** (0.057)				
log_DALYs_2010*Eastern_Africa		0.26*** (0.071)	0.32** (0.15)	0.30** (0.15)	0.077*** (0.026)
log_DALYs_2010*Northern_Africa		0.38*** (0.077)	0.31** (0.15)	0.28* (0.16)	0.037 (0.027)
log_DALYs_2010*Southern_Africa		0.38*** (0.089)	0.39*** (0.13)	0.40*** (0.12)	0.031 (0.026)
log_DALYs_2010*West&Central_Africa		0.24*** (0.065)	0.27* (0.15)	0.24* (0.13)	0.015 (0.046)
Int_collab_11_15 (%)				1.26 (0.91)	0.032 (0.21)
log_Pubs_06.10					0.92*** (0.026)
Constant	4.52*** (0.38)	3.61*** (0.47)	3.15*** (1.03)	2.32* (1.20)	0.50** (0.25)
Regional dummies	No	No	Yes	Yes	Yes
Observations	103	103	103	103	103
R-squared	0.082	0.222	0.226	0.242	0.958

Note 1: Robust standard errors in parentheses;

Note 2: In estimations 2–4, the regression model is computed controlling for four regions: Eastern Africa, Northern African, Southern Africa and West & Central Africa.

*** $p < 0.01$,

** $p < 0.05$,

* $p < 0.1$.

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