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Research and innovation in West Africa: an informetric analysis within the framework of the Triple Helix model

Onderzoek en innovatie in West-Afrika: een informetrische analyse in het kader van het Triple Helix-model

Proefschrift voorgelegd tot het behalen van de graad van doctor in de informatie-en bibliotheekwetenschap aan de Universiteit Antwerpen te verdedigen door

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To you
Whoever you are
And to my sons
That have great expectation in me

Onderzoek en innovatie in West-Afrika: een informetrische analyse in het kader van het Triple Helix-model

Samenvatting

Dit proefschrift ontwikkelt een methode om te evalueren welke bijdrage onderzoek aan innovatie levert en dus aan economische groei in het algemeen en de kenniseconomie in het bijzonder. Het is gebaseerd op het Triple Helix-model van innovatie en is geografisch beperkt tot de vijftien West-Afrikaanse landen, die allemaal lid zijn van de Economische Gemeenschap van West-Afrikaanse Landen (ECOWAS), het grootste regionale samenwerkingsverband in dit deel van Afrika.

De Triple Helix is een variant van het niet-lineaire model van innovatie, wat stelt dat innovatie het resultaat is van wisselwerkingen tussen Universiteit, Industrie, Overheid en hun omgeving. Volgens het Triple Helix-model zorgen de relaties tussen de drie actoren voor een kennisinfrastructuur die kennis genereert. De verspreiding hiervan leidt tot innovatie. Het model verklaart en benadrukt het belang van kennisproductie en -deling in economische groei. Het is, met andere woorden, in overeenstemming met het concept van de op kennis gebaseerde economie.

De relaties tussen universiteit, industrie en overheid vormen een complex systeem dat bestudeerd kan worden met technieken en methodes uit verschillende disciplines, zoals informatietheorie, sociale-netwerkanalyse en speltheorie. Oorspronkelijk meet de wederzijdse informatie, ontleend aan Shannons informatietheorie, de hoeveelheid informatie die twee variabelen in netwerkcommunicatie gemeenschappelijk hebben. De wederzijdse informatie wordt in de Triple Helix-analyse gebruikt om aan te geven hoe centraal gestuurd een innovatiesysteem is. Het geeft eveneens aan in welke mate een economie op kennis gebaseerd is.

Het doctoraatsproefschrift bestudeert het complexe systeem van de Triple Helix van Universiteit–Industrie–Overheid relaties vanuit informatietheoretisch oogpunt. We beschouwen de U-I-G relaties als een informatiebron en tonen aan dat zo'n bron met n willekeurige variabelen kan worden opgedeeld in 2n of 2n – 1 "staten". Bijgevolg kan de maximale entropie van de bron berekend worden. De boven- en ondergrenzen aan de wederzijdse informatie worden bepaald,. Vervolgens wordt een normalisatie van de wederzijdse informatie voorgesteld die we transmissievermogen noemen, als indicator van de Triple Helix van U-I-G relaties.

Het transmissievermogen meet de efficiëntie van de wederzijdse informatie. Het geeft het stuk deelbare informatie aan dat effectief in een innovatiesysteem gedeeld wordt. Anders gezegd, het is de sterkte van de uitwisseling van informatie en kennis tussen variabelen. De berekening van het transmissievermogen kan plaatsvinden op het niveau van een regio (lokaal), op het niveau van innovatieactoren in partnerlanden (buitenlands), of beide (globaal). Dit onderscheid is nodig om het

effect te berekenen van internationale samenwerking op kennisstromen binnen het innovatiesysteem van een regio.

Dit theoretisch kader wordt toegepast op de regio van West-Afrika.

We beschrijven eerst het kader van wetenschappelijke publicaties in de West-Afrikaanse regio door de kenmerken te bestuderen van de publicaties uit de regio die in Web of Science zijn geïndexeerd: de jaarlijkse output, de taal en het type van de productie, het gebied van de productie, de patronen van co-auteurschap, de mate van internationale samenwerking, de belangrijkste partnerlanden, citeerbare documenten en de h-index. We vergelijken het wetenschappelijke profiel van de West-Afrikaanse regio met dat van Brazilië, India, China en Zuid-Afrika over een periode van tien jaar (2001-2010). Hoewel de jaarproductie van West-Afrika in een opwaartse trend zit, blijft ze te laag in vergelijking met de wereldproductie. De belangrijkste Afrikaanse partnerlanden zijn Zuid-Afrika (in Zuidelijk Afrika), Kameroen (in Centraal-Afrika), Kenia en Tanzania (in Oost-Afrika). De belangrijkste niet-Afrikaanse partnerlanden zijn Frankrijk, de VS en het Verenigd Koninkrijk, die samen hebben bijgedragen tot meer dan 63% van de papers met een niet-West-Afrikaans adres, wat illustreert hoezeer de regionale wetenschapsbeoefening naar buiten is gericht. Individuele landen hebben een hogere graad van internationale samenwerking, met uitzondering van Nigeria. West-Afrikaanse landen hebben minder samengewerkt met elkaar en ook minder met Afrikaanse landen en ontwikkelingslanden dan met ontwikkelde landen.

In West-Afrika is de universiteit de grootste producent van kennis, gevolgd door overheid en industrie. Het aantal industriële publicaties is verwaarloosbaar; sommige landen hebben er zelfs geen. Bijgevolg is de samenwerking tussen de universiteit en de overheid beter zichtbaar. Op het niveau van de afzonderlijke landen hebben alle 15 lidstaten gegevens over samenwerking tussen universiteiten en de overheid, maar alleen in Nigeria en Ghana heeft het bedrijfsleven samenwerkingen met overheid of universiteit. Deze twee landen zijn de grootste producenten van informatie binnen de regio. Enkel in Nigeria was er samenwerking tussen de drie Triple Helix-actoren. De wederzijdse informatie tussen universiteit, bedrijfsleven en overheid is zwak zowel op regionaal als nationaal niveau, wat wordt aangetoond door het lage niveau van synergie tussen de actoren in de regio.

De wederzijdse informatie en het transmissievermogen worden gebruikt als indicatoren van de kenniscirculatie tussen West-Afrikaanse innovatie-actoren. Ze tonen aan dat minder dan 10% van de kennis geproduceerd binnen het West-Afrikaanse innovatiesysteem wordt gedeeld tussen innovatie-actoren. Vervolgens zoeken we een correlatie tussen het transmissievermogen en andere indicatoren om de kenniseconomie te meten. Voor de gevalstudie selecteren we zes OESO-landen (de VS, Canada, Frankrijk, Duitsland, Japan en Zuid-Korea) en zes indicatoren: de bruto-uitgaven voor onderzoek en ontwikkeling (GERD) als percentage van het bruto binnenlands product (BBP), het aantal onderzoekers, de groei van het bruto binnenlands product (BBP), het bruto binnenlands product per hoofd van de bevolking (BBP per hoofd van de bevolking), Human Development Index (HDI) en Total Factor Productiviteit (TFP). Japan en Zuid-Korea vertonen een sterke positieve correlatie tussen transmissievermogen en de GERD enerzijds en tussen transmissievermogen en het aantal onderzoekers anderzijds. Beide landen hebben hetzelfde patroon betreffende het transmissievermogen en elk van de geselecteerde indicatoren; andere landen laten geen vergelijkbaar patroon zien. De analyse leidt tot de conclusie dat het transmissievermogen berekend op enkel het nationaal niveau niet volstaat om te meten in welke mate een economie een kenniseconomie is, omdat het geen rekening houdt met de synergie en de kennisbijdrage op internationaal niveau door de innovatieactoren uit het land.

Om het effect te bestuderen van internationale samenwerking op de synergie en de creatie en circulatie van kennis in een innovatiesysteem, werden drie niveaus van analyse onderscheiden: het binnenlandse niveau dat de innovatie-actoren van het land of het studiegebied groepeert, het buitenlandse niveau dat institutionele partners groepeert en het wereldwijde niveau dat de innovatie-actoren van zowel binnenlandse als buitenlandse niveaus samenvoegt. We postuleren dat de kennis die circuleert in een innovatiesysteem wordt bepaald door het wereldwijde transmissievermogen omdat het de kennisinbreng uit internationale samenwerking integreert. Het wereldwijde transmissievermogen is daarom beter geschikt om landen te vergelijken.

Uit de wederzijdse informatie en het transmissievermogen berekend voor de drie niveaus voor Zuid-Korea en West-Afrika is gebleken dat het West-Afrikaanse innovatiesysteem minder geïntegreerd is dan zijn institutionele partners, terwijl het Zuid-Koreaanse innovatiesysteem op zichzelf meer is geïntegreerd. Het binnenlandse transmissievermogen varieert van 3 tot 7% in Afrika en schommelt rond 20% in Zuid-Korea. Dit betekent dat in West-Afrika 3 tot 7% van de uitwisselbare informatie en kennis circuleert onder innovatie-actoren (tegenover 20% in Zuid-Korea) . Algemeen heeft West-Afrika tot 100% aan kennisuitwisseling bij gekregen binnen zijn innovatiesysteem als gevolg van internationale samenwerking en Zuid-Korea 20%. De grote afhankelijkheid van de West-Afrikaanse regio van internationale samenwerking (50% tegenover 20% voor Zuid-Korea) verklaart dit effect op het informatie- en kennisverkeer binnen het West-Afrikaanse regionale innovatiesysteem.

Research and innovation in West Africa: an informetric analysis within the framework of the Triple Helix model

Abstract

This doctoral dissertation provides a method to evaluate the contribution of research to innovation and, hence, to economic growth in general and the knowledge-based economy in particular. It is based on the Triple Helix model of innovation and has as geographical framework the fifteen West African countries, all members of the Economic Community of the West African States (ECOWAS), the largest regional integration space in this part of Africa.

The Triple Helix is a variant of the nonlinear model of innovation, which postulates that innovation results from interactions between University, Industry, Government and their environment. According to the Triple Helix model, the relationships between these three actors maintain a knowledge infrastructure that generates knowledge whose distribution leads to innovation. The model explains and stresses the importance of knowledge production and sharing in economic growth; in other words, it is compliant with the concept of the knowledge-based economy.

The University-Industry-Government relationships constitute a complex system that can be studied with tools and techniques from different disciplines, e.g. information theory, social network analysis and game theory. Originally, the mutual information borrowed from Shannon's information theory measures the quantity of information common to two variables in a network communication. It is based on the notion of entropy, which measures the quantity of information contained within a variable. The mutual information is introduced in the Triple Helix relationship analysis to indicate the synergy within an innovation system or determine how centrally controlled an innovation system is. It also indicates the extent to which an economy is knowledge-based.

The doctoral thesis studies the complex system of the Triple Helix of University-Industry-Government relationships from the information theory point of view. It considers the University-Industry-Government relationships as an information source and demonstrates that such a source with n random variables can be split into 2^n or $2^n - 1$ "states". Therefore, the maximum entropy of the source can be computed. The upper and lower bounds to the mutual information are determined; then, the normalisation of the mutual information is proposed under the name *transmission power*, as an indicator of the Triple Helix of University-Industry-Government relationships.

The transmission power measures the efficiency of the mutual information. It indicates the part of the sharable information that is really shared within an innovation system; in other words, it denotes the strength of the circulation of information and knowledge between variables. The transmission power can be

calculated at either the area level (domestic) or the partner countries' innovation actor level (foreign) or both (global). This distinction is needed to compute the effect of international collaboration on knowledge flow within an area's innovation system.

This theoretical framework is applied to the West African region.

We first describe the landscape of scientific publishing in the West African region by studying the characteristics of the Web of Science-indexed publications produced by the region: annual output, language and type of production, fields of production, co-authorship patterns, international collaboration rate, main partner countries, citable documents and h-index. We compare the scientific profile of the West African region to that of Brazil, India, China and South Africa over a ten-year period (2001-2010). Even though the annual output of West Africa is trending upward, it remains too low when compared to the global output. The main African partner countries are South Africa (Southern Africa), Cameroon (Central Africa), Kenya and Tanzania (Eastern Africa). The main non-African partner countries are France, USA and the United Kingdom, which on their own contributed to over 63% of the papers with a non-West African address, illustrating the extraversion of the regional science. Individual countries have higher international collaboration rates, except for Nigeria. West African countries cooperated less with each other and less with African and developing countries than they did with developed ones.

In West Africa, University is the biggest science producer followed by Government and Industry. However, the number of industrial publications is negligible, with some countries even having no industrial output at all. Consequently, collaboration between University and Government is more visible. At the level of individual countries, all 15 member states have data on joint University / Government collaborations, whereas publishing collaborations between Industry and Government or University are only found in Nigeria and Ghana, the two biggest information producers within the region. Collaborations between the three Triple Helix actors occurred only in Nigeria. The mutual information between University, Industry and Government at both regional and national levels is weak, illustrating the low level of synergy among the actors in the region as far as scientific publishing is concerned.

Mutual information and transmission power are used as indicators of knowledge circulation between West African innovation actors. The results reveal that less than 10% of the knowledge produced within the West African innovation system is shared between the innovation actors. Subsequently, we investigated possible correlations between the transmission power and a number of indicators used to measure the knowledge-based economy. For the case study, we selected six OECD countries (USA, Canada, France, Germany, Japan and South Korea) and six indicators: Gross Expenditure for Research and Development as a percentage of Gross Domestic Product (GERD), number of researchers, Gross Domestic Product (GDP) growth rate, Gross Domestic Product per capita (GDP per capita), Human Development Index (HDI) and Total Factor Productivity (TFP). Japan and South Korea exhibit a positive strong correlation between transmission power and GERD on the one hand and transmission power and number of researchers on the other hand. These two countries display similar patterns regarding transmission power and each of the selected indicators; other countries do not show any comparable patterns. The analysis allows us to conclude that i) the transmission power computed at national level only is not sufficient to measure the extent to which an economy is knowledge-based, because it does not take into account the synergy and the knowledge contributed at international level by the innovation actors of a nation and ii) the transmission power captures a dynamic that is not present in other indicators.

In order to study the effect of international collaboration on the synergy and knowledge creation and circulation in an innovation system, three levels of analysis were distinguished: the domestic level pooling the innovation actors operational in the country or the area under study, the foreign level grouping the institutional partners and the global level merging the innovation actors from both domestic and foreign levels. We postulated that the knowledge that circulates within an innovation system is determined by the global transmission power because it integrates the knowledge contributed due to international collaboration. The global transmission power is therefore a more suitable indicator for comparison between countries.

The mutual information and transmission power computed at the three levels for South Korea and West Africa revealed that the West African innovation system is less integrated than its institutional partner –even though the latter come from different horizons– whereas the South Korean innovation system is more integrated by itself. The domestic transmission power varies from 3 to 7% in Africa and amounts to ~ 20% in South Korea, i.e., in West Africa, 3 to 7% (against 20% in South Korea) of the sharable information and knowledge circulates among the innovation actors. Globally, West Africa has gained up to 100% in knowledge flow within its innovation system due to international collaboration and South Korea 20%. The high dependence of the West African region on international collaboration (50% against 20% for South Korea) explains this effect on information and knowledge circulation within the innovation system of the West African region.

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1. Introduction

1.1. Bibliometrics and the measurement of science

Nowadays, in the scientific literature, several terms such as bibliometrics, scientometrics, webometrics, informetrics, technometrics and, recently, altmetrics, are used to designate the application of mathematical and statistical techniques and methods to documents or information. Even though all of them share mathematical and statistical techniques and methods, they do not all apply to the same type of resource or information source.

According to Pritchard (1969), the term statistical bibliography had been used to describe the process of illuminating the history of science and technology by counting documents until he proposed the term *bibliometrics*. He defined bibliometrics as the application of mathematical and statistical methods to books and other media. However, Rousseau (2009, 2014) recalled that Paul Otlet had yet appealed for a new discipline he named *bibliométrie*[1] in his *Traité de documentation* (1934). The term bibliometrics was used in the West whereas at the same time the word scientometrics was in the East (Brookes, 1988, p. 29; Egghe & Rousseau, 1990b, p. 2). Coined in Russia by Vassili V. Nalimov (Braun, 2001, p. 101),[2] the term "Naukometriya" – translated into English as scientometrics – is defined as the study of the measurement of scientific and technological progress.

Informetrics first proposed by Nacke (1979) was adopted by the former Soviet All-Union Institute for Scientific and Technical Information (VINITI) as a generic term to embrace both bibliometrics and scientometrics (Brookes, 1990, p. 42). Its objectives are, according to VINITI, the provision of reliable data for research and development, for policy-making and planning, and for the management of institutions, projects, programmes, and activities. Tague-Sutcliffe (1992) defined informetrics as "the study of the quantitative aspects of information in any form, not just records or bibliographies, and in any social group, not just scientists. Thus it looks at the quantitative aspects of informal or spoken communication, as well as recorded, and of information needs and uses of the disadvantaged, not just the intellectual elite". According to Egghe and Rousseau (1990b, p. 3), informetrics, including bibliometrics, scientometrics, citation analysis and theoretical aspect of information retrieval, "borrows tools (techniques, models, analogies) from mathematics, physics, computer science and others metrics and applied to library management, sociology of science, history of science, science policy and information retrieval". A literature review of the history of the three terms (bibliometrics, scientometrics and informetrics) is given by Hood and Wilson (2001).

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[1] *Bibliométrie* is the French equivalent of the English *bibliometrics*.

[2] A special issue of the journal Scientometrics (volume 52, issue 2, 2001) was dedicated to the memory of Vassily Vassilievich Nalimov.

Besides these 'traditional terms', several other –metrics terms flourished, mainly at the advent and the popularization of the internet; they are *netometrics, webometry, internetometrics, webometrics, cybermetrics, Web bibliometry* (cf. Björneborn & Ingwersen, 2004, p. 1217). They were intended to designate the application of the bibliometrics techniques to the new media resources. Each of them was proposed by different authors; but webometrics and cybermetrics were the most used (Björneborn & Ingwersen, 2004); others have disappeared now.

Webometrics designates "the study of the quantitative aspects of the construction and use of information resources, structures and technologies on the Web drawing on bibliometric and informetric approaches" (Björneborn & Ingwersen, 2004, p. 1217). The authors added that this discipline covers "quantitative aspects of both the construction side and the usage side of the Web embracing four main areas of present webometric research: 1) Web page content analysis; 2) Web link structure analysis; 3) Web usage analysis (including log files of users' searching and browsing behaviour); 4) Web technology analysis (including search engine performance) » (p. 1217).

In the same framework, *cybermetrics* is defined as a generic term for "the study of the quantitative aspects of the construction and use of information resources, structures and technologies on the *whole* Internet drawing on bibliometric and informetric approaches" (p. 1217). It encompasses statistical studies of discussion groups, mailing lists, and other computer mediated communication on the Internet *including* the Web. Besides covering all computer-mediated communication using Internet applications, it also covers quantitative measures of the Internet backbone technology, topology, and traffic (p. 1217). Webometrics is therefore, included into cybermetrics. Björneborn and Ingwersen (2004, p. 1217) proposed Figure 1-1 to illustrate the relations between the information science metrics subfields.

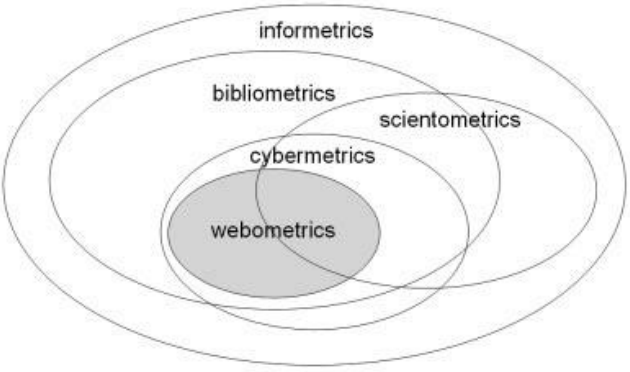

Figure 1-1 Relationships between the LIS fields of "-metrics".
Source : Björneborn and Ingwersen (2004, p. 1217)

With the rise of social media, another metric term has emerged: altmetrics. It is defined as “the creation and study of new metrics based on the Social Web for analysing, and informing scholarship”; its vision is summarized in a manifesto (Priem, Taraborelli, Groth, & Neylon, 2010). Altmetrics “refers to the use of social media, particularly Web 2.0 media, in assessing the influence of researchers on all type of users” (Rousseau & Ye, 2013, p. 3288) so that Priem and Hemminger (2010) could speak of “scientometrics 2.0”. In fact, the idea behind altmetrics is the same as the one behind informetrics. Altmetrics is a new form of informetrics (Rousseau & Ye, 2013, p. 3289). Moreover, it is informetrics applied to the new information sources social media are. As such, it is included in informetrics. Because its sources are social media that are mainly web-based, altmetrics is part of webometrics.

Patent is another source of information bibliometrics techniques are applied to. The term technometrics is then used. It serves in direct measurement of technological innovation (Archibugi & Sirilli, 2001).

In summary, based on Brookes’s (1988, 1990) definition, Egghe and Rousseau (1990b) agreed to use bibliometrics for documentation and scientometrics for sciences studies. Informetrics is the broader term that comprises all-metrics studies related to information science (Egghe, 2005, p. 1311; Rousseau & Ye, 2013, p. 3288).

Guns (2013) argued that informetrics has three dimensions; i) the documentary dimension (documents), ii) the social dimension (people and groupings of people), and iii) the epistemic or cognitive dimension (topics and ideas). As Le Coadic (1994) stated about information science, informetrics has become a science for years because it has an epistemology (a specific concept, models, methods, etc.), societies (e.g. the International Society for Scientometrics and Informetrics), journals (e.g. Scientometrics, Journal of informetrics) and scientific events (e.g. the ISSI biannual conferences of which the first two were held respectively in 1987 (Egghe & Rousseau, 1988) and 1989 (Egghe & Rousseau, 1990a)). Figure 1-2 presents the subjects and research areas of informetrics as proposed by Stock and Weber (2006, p. 385). Informetrics therefore, works with “information” whatever the source or medium is. It is used, among others, to assess research output or research policy.

The challenge of informetrics is to reveal the relation between scientific outputs and the scientific, technological and economic development; it faces this challenge though models (Courtial, 1990, p. 11).

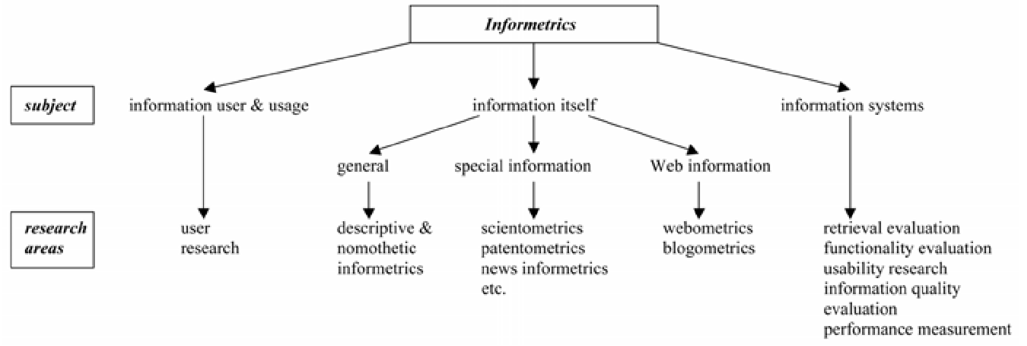

Figure 1-2 Subjects and research areas of informetrics.
Source: Stock and Weber (2006, p. 385)

1.2. Information and knowledge

The term information has contents and meanings that vary across disciplines, so that Le Coadic (1994, p. 8) wrote that the concept "has been taking a chameleon form" and Buckland (1991) affirmed that the term bears an ambiguity. Fortunately, whatever the discipline is, the ultimate objective of information is conveying knowledge throughout messages (Bates, 2005). In information science, difference is made between data, information and knowledge; even a hierarchy was introduced: data is symbols with no meaning; information adds meaning to data, and knowledge is information processed, structured, and organized, or information ready to be applied, to be put in action (Bates, 2005; Buckland, 1991). Knowledge is an exclusively cognitive phenomenon. Information or knowledge is intangible; in other words, "one cannot touch it or measure it in any direct way" (Buckland, 1991). However, Shannon (1948) proposed an *information theory* framework to measure the quantity of information contained in a message. In this theory, data is defined in terms of thermodynamic (physical) entropy, information in terms of Shannon (symbol) entropy, and knowledge in terms of cognitive (context) entropy (Boisot & Canals, 2014).

1.3. Research and innovation

1.3.1. Defining research

Research related activities encompass all works that contribute to knowledge creation. The Frascati Manual (OECD, 2002b, para. 63) states that research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. It covers three activities: basic research, applied research and experimental development. Basic research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.

Applied research is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. Experimental development is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed. R&D covers both formal R&D in R&D units and informal or occasional R&D in other units (OECD, 2002b).

1.3.2. Defining innovation

The Oslo Manual (OECD & EUROSTAT, 2005) defines innovation as «the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations». In other words, innovation supposes new things, new ways of doing, creativity, added value (OECD & EUROSTAT, 2005, para. 146). The manual recognizes that innovation may occur in any sector of the economy, including government services such as health or education (OECD & EUROSTAT, 2005, para. 27). Four types of innovations are distinguished at the level of the firm: product, process, organisational and marketing. Innovation improves performance and quality; it makes firms competitive. Innovation involves the utilization of new knowledge or a new use or combination of existing knowledge (OECD & EUROSTAT, 2005, p. 35). Therefore there is a relation between innovation that “consumes knowledge” and research activities that also consume knowledge but produce new one. Innovation has become synonym of modernity (Frietsch, 2008, p. 1). It drives economic growth and social welfare.

Innovation can be measured. Several indicators are used to this end; they relate to research and experimental development (such as number of publications, research collaboration, research funding, research equipment, number of researchers, etc.), number of patents, acquisition of external knowledge and technology, and intangible assets (such as software, human capital and new organisational structures) (cf. OECD, 2010; OECD & EUROSTAT, 2005, pp. 92–94): each measures only a particular aspect of innovation, that explains the complexity of the task. The OECD and the EUROSTAT (2005, pp. 33–37) proposed a framework for the measurement of innovation. Figure 1-3 depicts this framework from the perspective of the firm. It shows the four types of innovation at the firm level, on the one hand, and on the other hand, the interactions between the firm and other actors like other firms, education and research institutions, innovations policies, consumers, and infrastructure and institutional framework. Models have also been proposed to explain how innovation is generated and how it contributes to economic growth and social welfare.

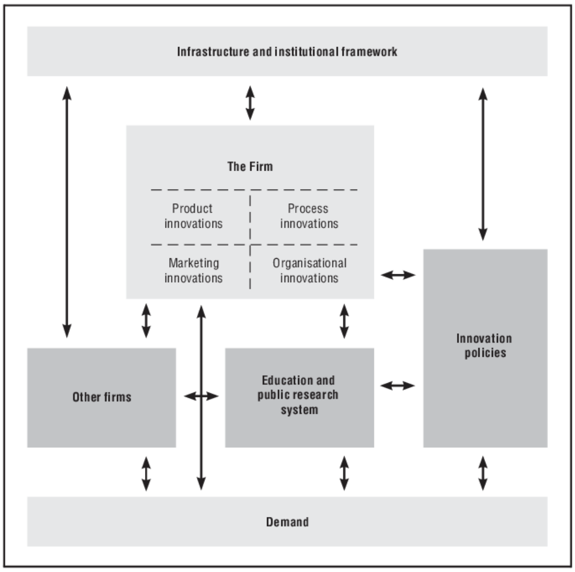

Figure 1-3 The OECD and EUROSTAT innovation measurement framework
Source: OECD & EUROSTAT (2005, p. 34)

1.3.3. Models of innovation

Two types of models of innovation were proposed up to now to explain the functioning of an economy: the linear and the nonlinear models. Each explains how growth is generated. Both models have been criticized (Godin, 2005, 2006b, 2007) and variants of them were proposed. The linear model postulated that “innovation starts with basic research, is followed by applied research and development, and ends with production and diffusion” (Godin, 2005, 2006b, 2014). The linear model has developed over times upon criticisms from researchers, industrialists and economists. The moderate criticisms were mainly on the steps towards innovation. If all of the criticisms agreed that basic research is the root and commercial use the final stage of innovation, the intermediary steps were discussed. For example, Maclaurin (1953) identified five steps: pure science, invention, innovation, finance, acceptance (or diffusion).

Major criticisms questioned the linearity of innovation and affirmed that innovation is not the result of a linear process (Kline, 1985) but rather a complex one between several institutions. The nonlinear model, an alternative to the linear model, introduced with the national innovation system concept “suggests that the research system’s ultimate goal is innovation and that the system is a part of a larger system composed of sectors like Government, University and Industry and their environment. The system also emphasized the relations between the components or sectors as the “cause” explaining the performance of innovation systems” (Godin, 2007, p. 5).

The model first focused on the institutional framework and relations, but shifted later to the process of knowledge creation and diffusion by the same institutions, leading to one of its variants, the knowledge-based economy framework (Godin, 2007, p. 7). Gibbons et al. (1994) introduced the Mode 1 and the Mode 2 of knowledge production. The Mode 1 is characterized by the absence of interactions between academia and the society; the Mode 2 weakens the role of university as knowledge producer and the collapse of the modern university (cf. also Nowotny et al., 2003). Conversely, the Triple Helix model focuses on the overlay of communications and expectations between University, Industry and Government.

In the national innovation system model, analysis focuses on the flows of knowledge between actors (OECD, 1997, p. 11).

1.4. The Triple Helix model of innovation

The Triple Helix laid down by Etzkowitz and Leydesdorff (1995, 2000) is one of the variants of the nonlinear model of innovation (cf. Etzkowitz & Leydesdorff, 2000; Leydesdorff, 2012b, p. 26; Meyer et al., 2014, p. 153). It postulates that the interactions between University, Industry and Government maintain a knowledge infrastructure that generates knowledge of which circulation among innovation actors leads to innovation (Leydesdorff & Etzkowitz, 2001). It differs from other variants of the innovation system by i) stressing the changing role of the actors, ii) considering the relations between University, Industry and Government as a communication system and, iii) focusing on the “overlay of communications and expectation” that reshapes the institutional arrangements among actors (Etzkowitz & Leydesdorff, 2000, p. 109). The Triple Helix model reduces the number of innovation actors to the three main ones whereas the innovation system model adds others like financial institutions.

According to the OECD (2002a, p. 15), the concept of interaction between innovators includes three basic ideas: i) competition, which is the interactive process where the actors are rivals and which creates the incentives for innovation, ii) transaction, which is the process by which goods and services, including technology embodied and tacit knowledge are traded between economic actors, and iii) networking, which is the process by which knowledge is transferred through collaboration, co-operation and long term network arrangements. The Triple Helix model relies on collaboration between innovation actors for knowledge creation, sharing and transformation purposes.

This thesis works on the model of the Triple Helix because i) the model deals with knowledge generation and circulation within innovation systems which is central to our objective; ii) it relates to the new economy also called the knowledge-based economy; indeed, through innovation, new knowledge is created and diffused, expanding the economy’s potential to develop new products and more productive methods of operation (OECD & EUROSTAT, 2005, p. 35); iii) its geographic audience is very broad compared with that of other variants like the Mode 2 (Shinn, 2002, p. 603), iv) it constitutes a serious research school with an empirical and conceptual agenda (Shinn, 2002, p. 611), v) national and international research funding institutions (like the North Atlantic Treaty Organisation, the European Union, National Science Foundation (USA), the Centre National de Recherche Scientifique (France), etc.) are interested, and vi) researchers from the Third World contribute to the development and the implementation of the theory; evidence could be established from the nationalities of participants to the annual Triple Helix conferences and authors of papers presented at the conferences.

1.5. Knowledge-based economy

In the post-industrial economy, innovation results mainly from creation, acquisition, diffusion and use of knowledge and not from industrial production (OECD, 2010, p. 21). This change in the innovation process led to the term knowledge-based economy.

The term was coined by the Organisation for Economic Co-Operation and Development (OECD) that defined it as an economy which is “directly based on the production, distribution and use of knowledge and information” (OECD, 1996, p. 7). It implies that economic growth, wealth creation and employment are driven essentially through the production, distribution and use of knowledge (APEC Economic Committee, 2000). It is not just the digital economy, which incorporates the production and use of computers and telecommunication equipment. It is not quite the networked economy, which incorporates the telecommunication and networking growth during the last decades and its impact on human progress (United Nations Economic Commission for Europe, 2002, p. v). It describes trends in advanced economies towards greater dependence on knowledge, information and high skill levels, and the increasing need for ready access to all of these by the business and public sectors (OECD & EUROSTAT, 2005, p. 28).

In fact, the economy has always been based on knowledge; indeed, even in the so called industrial economy (or traditional economy) mankind had needed knowledge in order to transform natural resource and contribute to economic growth, “because everything we do depends on knowledge” (World Bank, 1999, p. 16).

The knowledge-based economy is a complex phenomenon. For example, there are as yet no internationally accepted indicators to measure it. Hence international organisations use their own indicators that also vary from one year to another. For example, i) the OECD published several reports related to the knowledge-based economy (e.g. OECD, 1996, 1999, 2013); it used up to sixty indicators with variations from one publication to another; ii) the Word Bank established the Knowledge Economy Framework (Chen & Dahlman, 2005) which built two indicators: the Knowledge Economy Index (KEI) and the Knowledge Index (KI); iii) the Asian-Pacific Economic Cooperation defined the idealised knowledge-based economy but recognized that the given indicators are too idealistic and that not all its members could provide the statistics; iv) in 2010, the European Commission (2010b) published the innovation scoreboard which used twenty-six statistics; more recently, it has set up a composite index, the Summary Innovation Index – which summarizes the performance of a range of 25 different indicators (European Commission, 2014, p. 8); the objective is no longer a direct measurement of the knowledge based economy but rather innovation performance; v) the United Nations Economic Commission for Europe (2002) defined a framework to measure the knowledge-based economy and suggested the Global Knowledge-Based Economy Index (GKEI) as an indicator. On their side, researchers at individual level also proposed indicators. Arvanitidis and Petrakos (2011, p. 25) developed the Economic Dynamism Indicator, a composite index; the Centre for International Development (CID) at Harvard University proposed 19 indicators, and Leydesdorff (2003) built the mutual information or transmission as a measure of the interactions among innovation system actors.

1.6. Objectives and research questions

1.6.1. Motivations

Developing countries' contribution to world advancement in general is marginal in all domains. Particularly, in the domain of scientific research, Africa's share to the world science is negligible (less than 1%, cf. Adams et al., 2010). Moreover, this part of the world is the poorest, in terms of wealth production; it is also facing the biggest challenges: poverty, hunger, armed conflicts, governance, population growth, access to education and health cares, etc.

Science in Africa, in general, and West African countries in particular, depends strongly on international collaboration (cf. Adams et al., 2014; Adams et al., 2010; Mêgnigbêto, 2013a; Tijssen, 2007; Toivanen & Ponomariov, 2011) owing to the weaknesses in both the institutional framework and science funding and equipment. Consequently, research is done in the shade or the wake of development projects and programmes financed by donors (Bierschenk & Mongbo, 1995) meaning the majority of research these countries conduct is contributed to or initiated by foreign countries. So, there is a need to understand the extent to which the knowledge produced by West-Africa-based researchers helps the region in wealth creation. More generally, the policy challenges that policy makers face require a solid understanding of the mechanisms that may help to improve the current situation.

1.6.2. Objectives

Our research aims to measure how research contributes to innovation in West Africa. Particularly, it intends to study how innovation actors collaborate in knowledge creation and sharing in order to contribute to the economic and social development of the region.

The specific objectives are to:

1. describe the landscape of scientific publishing in West Africa by analysing the scientific output of the region with respect to annual research output, language and publication type, scientific fields and co-authorship.
2. study the collaboration pattern in West African scientific publishing by determining the annual collaboration rates of the West African countries and the main partner countries of West Africa in terms of country, region as well as continent;
3. determine the extent to which West African innovation actors collaborate towards knowledge creation and sharing both at country level and regional level;
4. propose a method to measure knowledge circulation among innovation actors; and,
5. measure the extent to which knowledge is created and shared between innovation actors both at individual country level and regional level.

1.6.3. Research questions

The main research question is: How does research contribute to innovation and hence to the knowledge-based economy in West Africa? It includes the following:

1. What are the characteristics of the scientific output in West Africa?
2. To which extent do West African countries collaborate with each other or with the rest of the world regarding scientific publishing?
3. How do innovation actors collaborate in scientific publishing in West Africa?
4. How can knowledge circulation among the innovation actors be measured?
5. How is knowledge produced and circulated within the West African innovation systems?

To answer these research questions, we collected bibliographic references of West African countries' scientific publications over a ten-year period (2001-2010) from the Web of Science, an international multidisciplinary database.

1.7. Structure of the study

The dissertation is structured in ten chapters as follows:

- Chapter 1 (this one) introduces the theme: bibliometrics, informetrics, research, innovation and knowledge-based economy;
- Chapter 2 presents the West African region, its Member States, gives basic data on individual countries, presents the regional integration institutions

and programmes, and the challenges the region is facing by the means of basic statistics and information;

- Chapter 3 deals with the scientific profile of the West African region and compares it with other regions or countries from Africa or the world;
- Chapter 4 relates to the international and intraregional collaboration in West African science publishing;
- Chapter 5 focuses on research collaboration between University, Industry and Government, the main innovation actors;
- Chapter 6 elaborates the transmission power as an indicator of knowledge flow between innovation actors;
- Chapter 7 applies the transmission power (as introduced in chapter 6) to measure the knowledge flow within the West African innovation systems;
- Chapter 8 compares six OECD economies with regard to the transmission power and tests whether there is any correlation between this indicator and those used to measure the knowledge-based economy; and finally,
- Chapter 9 enlarges the notion of information flow to include the effect of international collaboration,
- Chapter 10 concludes by summarizing the main findings of the thesis and its limitations, and discusses suggestions for future research and policy implications.

Each chapter (from 3 to 9) formulates its own research question(s), builds its method, collects and treats its data. Each is written to be read independently.

2. West Africa: basic data

2.1. Introduction

The African continent counts 55 countries, including the Western Sahara recognized as a state by the African Union, but not yet by the United Nations Organization. Except Morocco which has left the Union for political reasons, [3] all the African countries are member of the African Union.

The African Union has divided the African continent into five regions[4] taking into account historical, cultural and geographical criteria. They are the Northern (6 countries), the Western (15 countries), the Central (9 countries), the Eastern (14 countries) and the Southern (10 countries) (cf. Table 2-1). The African Union also established eight Regional Economic Communities (African Union Commission & New Zealand Ministry of Foreign Affairs and Trade, 2014, p. 118) to encourage regional integration within Africa, increase the flow of foreign investment into the continent and assist with sustainable economic development. They are: the Arab Maghreb Union (AMU), the Common Market for Eastern and Southern Africa (COMESA), the Community of Sahel-Saharan States (CEN-SAD), the East African Community (EAC), the Economic Community of Central African States (ECCAS), the Economic Community of West African States (ECOWAS), the Intergovernmental Authority on Development (IGAD) and the Southern African Development Community (SADC).

2.2. Geographical location

The West African region Member States are, in the alphabetic order: Benin, Burkina Faso, Cote d'Ivoire, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Nigeria, Niger, Senegal, Sierra Leone and Togo. The region is comprised within the inter-tropical area between the Equator and the Tropic of Cancer (5° South and 25° North) on the one hand, and the 20° West and 15° East on the other hand. It is bordered by the Atlantic Ocean in the South and the West, Mauritania, Morocco, Libya and Algeria in the North, and Chad and Cameroon in the East (Figure 2-1). The Southern part of the region, closer to the Equator, has a hot and humid climate with an abundant rainfall; it is covered with forests. The Northern part, the Sahel, is covered with savannahs and steppes. A large part of Mali, Niger and Senegal surface is covered by the Sahara desert; the climate is dry and the soils are arid.

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[3] Morocco left the Organisation of the African Union (OAU), now African Union, in November 1984 following the admission of the Sahrawi Republic in 1982 as the Government of Western Sahara (cf. African Union Commission & New Zealand Ministry of Foreign Affairs and Trade, 2014, p. 10).

[4] Resolution CM/Res.464 (XXVI) adopted by the African Unity Organization (now African Union) Council of Ministers meeting in its twenty sixth ordinary session in Addis-Ababa (Ethiopia) from 23 February to 1st March 1976. The countries list was updated in 2004.

Table 2-1 African countries per region (according to the African Union)

West Africa	East Africa	Southern Africa	Central Africa	Northern Africa
1. Benin	1. Comoros	1. Angola	1. Burundi	1. Algeria
2. Burkina Faso	2. Djibouti	2. Botswana	2. Cameroon	2. Egypt
3. Cape Verde	3. Eritrea	3. Lesotho	3. Centre Afr. Rep.	3. Libya
4. Cote d'Ivoire	4. Ethiopia	4. Malawi	4. Chad	4. Mauritania
5. Gambia	5. Kenya	5. Mozambique	5. Congo	5. Morocco[6]
6. Ghana	6. Madagascar	6. Namibia	6. Congo (DR)	6. Tunisia
7. Guinea	7. Mauritius	7. South Africa	7. Equatorial Guinea	
8.Guinea Bissau	8. Rwanda	8. Swaziland	8. Gabon	
9. Liberia	9. Seychelles	9. Zambia	9. Sao Tome & P	
10. Mali	10. Somalia	10. Zimbabwe		
11. Niger	11. South Sudan[5]			
12. Nigeria	12. Sudan			
13. Senegal	13. Tanzania			
14. Sierra Leone	14. Uganda			
15. Togo				

Figure 2-1 West Africa countries on an African map

[5] South Sudan became independent and joined the African Union on 27th July 2011. It belongs to the Eastern Africa.
[6] Even though Morocco is not member of the African Union, in this study, we included and classified it into the Northern region.

2.3. Political history

Before colonialism, the West African region was covered by several empires and kingdoms. The largest and strongest include Mali, Songhai, Wolof, Oyo, Ghana, Benin, Danxome, etc. Apart from Liberia which was set up by former enslaved Africans returning back from the USA, all the fourteen West African countries have been colonies of European Countries, namely France, Great Britain, Portugal and Germany. They all became independent around 1960 (and Cape Verde in 1975). They all continue however, to utilize European languages, a legacy of colonialism, as official language (Table 2-2) even though the region counts many local languages.

From their independence in the early 1960s to the end of the Cold War (end of 1980s), almost all the African States and hence all the West African States were ruled by single-party authoritarian regimes. Coups d'état occurred regularly leading to chronic political instability. The fall of the Berlin Wall in 1989 has changed geopolitical strategies at the international level, mainly in Western countries, and most of the developing countries in general and West African, in particular, were forced to switch over to democracy with a liberalized political and economic system. Almost all the West African countries adopted the republican form of State governance with institutional architecture borrowed from the Western Countries: a president, a government, a parliament and other institutions. However, the frustrations following the bad management of elections processes and litigations, the opportunist revisions of the fundamental laws, the non-respect of democracy rules, in a nutshell the absence of democratic culture and strengthened institutions, engendered coups (e.g. Niger in 1996, 1999 and 2010, Burkina Faso in 2015), armed conflicts (e.g. Cote d'Ivoire over 2002-2011), social and economic instability (e.g. Togo in 1991 onwards), or people's open insurrection that led to resignation (Burkina Faso in 2014). Political exclusion and natural resources management has fed armed conflicts in Liberia and Sierra Leone for over a decade (1988-2000) and in Mali (1990 onwards).

2.4. Regional integration in West Africa

Regional integration involves more than just economic matters. It goes beyond free movement of goods, capitals and persons and encompasses several other aspects like freedom of establishing oneself, doing business or being employed, benefiting from social services like education or health, insurance, etc. in any Member States as if one was in ones' own native country. The overall objective of a regional integration process is to make citizens' everyday life easier, and make people be citizen of a larger frontier-free space.

In order to achieve this goal, institutional and legal frameworks are usually set up; policies are conceived and applied both at national and regional levels. By engaging into a regional integration process, a country accepts to abandon a part of its sovereignty to the supranational authorities. According to Mahbub ul Haq, States-nation have become "too big for small things and too small for big things" (Horner, 1993, p. 5). Therefore, Member States of a regional integration community need to join their efforts at the regional level to tackle common problems they are facing; conversely, some problems didn't need supranational authorities' intervention before being resolved. These two faces of the same coin are best summarized by the *principle of subsidiarity* developed in the European integration law according to which the European Union must act where the objectives to be pursued can be better attained at the Union level (Borchardt, 2010, p. 41). More specifically, the principle of subsidiarity states that the supra-national level should only take care of those issues that cannot be dealt with at the national level. The principle of subsidiarity points out the requirement for elaborating and applying policies both at national and supra national levels to solve problems the community is facing.

Table 2-2 Capitals, former colonial powers, official languages and independence date of West African countries

#	Country	Capital	Former colonial power	Speaking language	Independence date
1	Benin	Porto-Novo	France	French	1st August 1960
2	Burkina Faso	Ouagadougou	France	French	5th August 1960
3	Cape Verde	Praia	Portugal	Portuguese	5th July 1975
4	Cote d'Ivoire	Yamoussoukro	France	French	7th August 1960
5	Gambia	Banjul	Great Britain	English	18th February 1965
6	Ghana	Accra	Great Britain	English	6th March 1957
7	Guinea	Conakry	France	French	2nd October 1958
8	Guinea Bissau	Bissau	Portugal	Portuguese	24th September 1973
9	Liberia	Monrovia	n/a	English	n/a
10	Mali	Bamako	France	French	22nd September 1960
11	Niger	Niamey	Great Britain	French	3rd August 1960
12	Nigeria	Abuja	Great Britain	English	1st October 1960
13	Senegal	Dakar	France	French	20th June 1960
14	Sierra Leone	Freetown	Great Britain	English	27th April 1961
15	Togo	Lome	France	French	27th April 1960

The regional integration process in West Africa started even under the colonial powers whose objectives were to gain maximal profit from the colonies. Just after the independence, the newly created states have joined different regional integration communities. The *Conseil de l'Entente* (Understanding Council) created in 1959 covers Benin, Burkina Faso, Cote d'Ivoire, Niger and Togo. The *Union Monétaire Ouest-Africaine* (West African Monetary Union, WAMU) created in 1962 has become *Union Economique et Monétaire Ouest Africaine* (West African Economic and Monetary Union, WAEMU, more known under its French acronym UEMOA) in 1996; it groups 8 countries : Benin, Burkina Faso, Cote d'Ivoire, Guinea Bissau, Mali, Niger, Senegal and Togo. It has had targets of free internal trade and a common external tariff, and in the longer term free movement of services, capital, and people, and harmonisation and mutual recognition of technical standards. Other regional organisations were created around water resources management. Examples are the *Organisation pour la Mise en Valeur du Fleuve Sénégal* (OMVS) grouping countries around the Senegal[7] river, the *Autorité du Bassin Niger* (ABN) grouping countries the river Niger goes through[8], or the Mano River Union (MRU)[9].

The largest regional integration organization in West Africa is the Economic Community of West African States (ECOWAS); it encompasses all 15 states of the region. While WAEMU's Member States have a common currency,[10] the remaining seven other countries each has its own currency. The WAEMU is more integrated and advanced through its successful adoption and implementation of regional policies but the ECOWAS has expertise in maintaining regional peace and security (Touré, 2014). These two regional integration areas have agreed on a joint strategy to speed up the process of integration in West Africa (GEA-African studies group, Garcia, & Seron, 2014, p. 8). The ECOWAS is the one that has a recognized political leadership; indeed, it is the unique Regional Economic Community in West Africa as distinguished by the African Union; it is also the one which represents the region with its international partners like the United Nations Organisation or the European Union.

2.5. ECOWAS, the regional integration area

The Economic Community of West African States (ECOWAS) groups together all the 15 countries of the West African region. In other words, the West African region, as defined by the African Union, and the ECOWAS coincide. It means that any member of the African region is also member of ECOWAS and vice-versa. If West Africa is often referred to from a political or geographic point of view, ECOWAS focuses on the regional integration process. In this thesis however, we utilize the two designations interchangeably.

2.5.1. Creation and objectives

The ECOWAS was established with the Treaty of Lagos (ECOWAS, 1975) signed on 28th May 1975 in Lagos. The Treaty was revised in 1993 (ECOWAS Commission, 1993) to enable the region to face new challenges. The organization aims at promoting economic cooperation and integration and regional security that should lead to an economic and monetary union through a complete integration of the economies of Member States. The end of these aims is to "raise the living standards of its peoples,

[7] There are Senegal, Gambia and Mali.
[8] There are Benin, Niger, Burkina Faso, Guinea
[9] The member states are Liberia, Sierra Leone and Guinea
[10] The common currency is the West African Franc of which in international code is XOF; it has a fixed parity with the European Union currency, the Euro, due to economic and political relations with France.

and maintain and enhance economic stability, foster relations-among Member States and contribute to the progress and development of the African Continent" (Article 3 of the Revised Treaty). ECOWAS Headquarters are established in Abuja (Nigeria). Later on, West Africa integration institutions and Member States have recognized democracy as a system that sustains peace, stability, economic growth, social and economic development and a condition to regional integration; they are committed to "deepen and strengthen the democratic institutions using appropriate international standards" with an "ECOWAS of people" as target (ECOWAS Commission, 2011b).

2.5.2. Institutional architecture

The organizational structure of the ECOWAS consists of the Authority of Heads of State and Government, the Council of Ministers, the Community Parliament, the Economic and Social Council, the Community Court of Justice, the Commission, and Specialized Technical Commissions (Article 6 of the Revised Treaty).

2.5.2.1. The Authority of Heads of State and Government

The Conference of Heads of State and Government is composed of Heads of State and/or Government of Member States. It is the supreme institution of the Community. It is responsible for the general direction and control of the Community and takes all measures to ensure its progressive development and the realization of its objectives. The Authority meets at least once a year.

2.5.2.2. The Council of Ministers

The Council comprises the Minister in charge of ECOWAS Affairs and any other Minister of each Member State. The Council is responsible for the functioning and development of the Community. To this end, unless otherwise provided in the Treaty or a Protocol, The Council makes recommendations to the Authority on any action aimed at attaining the objectives of the Community, and appoints all statutory appointees other than the Commission. By the powers delegated to it by the Authority, the Council issues directives on matters concerning coordination and harmonization of economic integration policies. It makes recommendations to the Authority on the appointment of the External Auditors, prepares and adopts its rules of procedure, and carries out all other functions assigned to it and exercise all powers delegated to it by the Authority. The Council meets at least twice a year.

2.5.2.3. The Community Parliament

The ECOWAS Parliament is essentially a consultative body. It provides advisory opinion on issues covering a wide range of areas that are of crucial importance for the integration process. These include respect for human rights, the interconnection of communication and telecommunication links, health, education, and revisions of basic community texts. The ECOWAS Parliament counts 115 seats distributed among the 15 ECOWAS Member States on the basis of their population (Table 2-3).

Table 2-3 Distribution of the Community Parliament seats per ECOWAS country

#	Country	Number of seats
1	Benin	5
2	Burkina Faso	6
3	Cape Verde	5
4	Cote d'Ivoire	7
5	Gambia	5
6	Ghana	8
7	Guinea	6
8	Guinea Bissau	5
9	Liberia	5
10	Mali	6
11	Niger	6
12	Nigeria	35
13	Senegal	6
14	Sierra Leone	5
15	Togo	5
	ECOWAS	**115**

Source: ECOWAS Parliament Website (http://www.parl.ecowas.int/parliament.html).

2.5.2.4. The Economic and Social Council

The Economic and Social Council is also an advisory body. It includes representatives of the various categories of economic and social activity of the countries.

2.5.2.5. The Court of Justice

The Court of Justice addresses complaints from Member States and institutions of ECOWAS, as well as issues relating to defaulting nations.

2.5.2.6. The Commission

The Commission, formerly Executive Secretary, is appointed by the Authority of Heads of States and Government for a four-year term, which may be renewed once only. It is led by a President assisted by two Vice Presidents. The President of the Commission directs the activities of the Commission; he is the legal representative of the Institutions of the Community in their totality. His duties include i) execution of decisions taken by the Authority and application of the regulations of the Council; ii) promotion of Community development programmes and projects as well as multinational enterprises of the region; iii) convening as and when necessary meetings of sectoral Ministers to examine sectoral issues which promote the achievement of the objectives of the Community; iv) d) preparation of draft budgets and programmes of activity of the Community and supervision of their execution upon their approval by Council; v) submission of reports on Community activities to all meetings of the Authority and Council; vi) preparation of meetings of the Authority and Council as well as meetings of experts and technical commissions and provision of necessary technical services; vii) recruitment of staff of the Community and appointment to posts other than statutory appointees in accordance with the Staff Rules and Regulations; viii) submission of proposals and preparation of such studies as may assist in the efficient and harmonious functioning and development of the Community; and ix) initiation of draft texts for adoption by the Authority or Council.

The Commission is composed of 15 commissioners designated by the Authority of Head of States and Government. It is headed by a President and a Vice-President.

2.5.2.7. Specialized institutions

The Technical Commissions are: i) Food and Agriculture; Industry, ii) Science and Technology and Energy, iii) Environment and Natural Resources, iv) Transport, v) Communications and Tourism, vi) Trade, Customs, Taxation, Statistics, Money and Payments, vii) Political, Judicial and Legal Affairs, Regional Security and Immigration, vii) Human Resources, Information, Social and Cultural Affairs, viii) Administration and Finance Commission.

Within its field of competence, each Technical Commission prepares Community projects and programmes and submits them for the consideration of Council through the Commission, either on its own initiative or at the request of Council or the Commission. It also ensures the harmonisation and co-ordination of projects and programmes of the Community, monitors and facilitates the application of the provisions of the treaty and related protocols pertaining to its area of responsibility, carries out any other functions assigned to it for the purpose of ensuring the implementation of the provisions of the Treaty.

2.5.3. Programmes and sectors

The ECOWAS prioritizes sectors that are energy, water, civil society, agriculture, infrastructures, health and social affairs (including education), information and communication technologies, telecommunications, trade and political affairs (ECOWAS Commission, 2015b). The Community formulated policies in the fields of agriculture in 2005 (ECOWAS Commission, 2005), industry in 2010 (ECOWAS Commission, 2010a), and science, technology and innovation in 2012 (Commission de la CEDEAO, 2012). It expressed its vision of an "ECOWAS of people" by 2020 (ECOWAS Commission, 2011b) and established a Regional strategic plan for the period 2001-2015 (ECOWAS Commission, 2011a). Six strategic pillars were articulated: (i) promote good governance and justice, (ii) strengthen mechanisms for conflict prevention, management and resolution; (iii) promote infrastructure development to support a competitive business environment, sustained development and cooperation in the region; (iv) deepen economic and monetary integration; (v) reinforce institutional capacity; and (vi) strengthen mechanisms for integration into the global market.

Several programmes are being executed in all sectors to strengthen to regional integration. In the sector of energy there are the West Africa Power Pool (WAPP) and the West Africa Gas Pipeline (WAGP). The WAPP aims to integrate the national power system operations into a unified regional electricity market - with the expectation that such mechanism would, over the medium to long-term, assure the citizens of ECOWAS Member States a stable and reliable electricity supply at affordable costs. The mandate of the WAGP is to transport natural gas from Nigeria to customers in Benin, Togo and Ghana in a safe, responsible and reliable manner, at prices competitive with other fuel alternatives.

The free movement of goods and persons and the establishment of ECOWAS citizens in any ECOWAS country are effective. ECOWAS launched a Trade Liberalization Scheme in 1990, and achieved a Custom union with a Common External Tariff in 2008 (ECOWAS Commission, 2015a). Positive strides have been made in the harmonization of macroeconomic policies, the implementation of the Common External Tariff (CET), multilateral surveillance, research and youth empowerment, trade liberalisation, customs union, favourable industrial policy, mines development, agriculture and environment, infrastructure-transport, telecommunications and energy. Soon, the Abidjan-Lagos Highway Project under the regional infrastructure development programme would be completed. Currently, the region counts 9 currencies (Table 2-4). A unique monetary zone and a single biometric identity card are scheduled for 2020 (ECOWAS Commission, 2012, p. 12).

Table 2-4 Currencies of West African countries

	Country	Currency
1	Benin	CFA Franc (XOF)
2	Burkina Faso	CFA Franc (XOF)
3	Cape Verde	Cape Verde Escudo (CVE)
4	Cote d'Ivoire	CFA Franc (XOF)
5	Gambia	Dalasi (GMD)
6	Ghana	Cedi (GHS)
7	Guinea	CFA Franc (XOF)
8	Guinea Bissau	CFA Franc (XOF)
9	Liberia	Liberian Dollar (LRD)
10	Mali	CFA Franc (XOF)
11	Niger	CFA Franc (XOF)
12	Nigeria	Naira (NGN)
13	Senegal	CFA Franc (XOF)
14	Sierra Leone	Leone (SLL)
15	Togo	CFA Franc (XOF)

2.5.4. *Challenges to regional integration*

Apart from the economic challenges and setbacks that the region has suffered over the decades, there have also been significant political challenges which have further exacerbated the economic condition in Member States. Some of those challenges include: political instability, conflicts, terrorism, endemic poverty, poor infrastructure and lack of political and institutional will. They have caused humanitarian disasters in many Member States, redirecting funding for development to addressing these pressing needs (Abass, 2013, pp. 26–29).

2.6. Demographic profile

The ECOWAS counts 337 million inhabitants (cf. Table 2-5) of which 40% have less than 15 years and half between 15 and 64 years. 52% of the West African people are female. The density of the population is 66 inhabitants per square kilometre; the annual population growth rate is 2.8%; about 47% of ECOWAS citizens live in an urban area. These last three indicators display strong differences between countries (cf. Table 2-6). As an illustration, Gambia is the densest country with 169 inhabitants per square kilometre and Mali and Niger have 12 to 14 inhabitants per square kilometre. The annual population growth rate, on the one hand, and the percentage of urban population, on the other hand, oppose Cape Verde at the first gear (0.9% and 64%) and Niger at the rear (2.9 and 18%) (cf. Table 2-6).

Table 2-5 Surface area, population and density of West African countries

#	Country	Surface area (thousand km^2)[11]	Population (million, 2014)[12]	Density
1	Benin	112.6	10.600	94.14
2	Burkina Faso	274.0	17.420	63.58
3	Cape Verde	4.0	0.504	124.97
4	Cote d'Ivoire	322.5	20.805	64.52
5	Gambia	11.3	1.909	169.01
6	Ghana	238.5	26.442	110.85
7	Guinea	245.9	12.044	48.99
8	Guinea Bissau	36.1	1.746	48.33
9	Liberia	111.4	4.397	39.48
10	Mali	1,240.2	15.768	12.71
11	Niger	1,267.0	18.535	14.63
12	Nigeria	923.8	178.517	193.25
13	Senegal	196.7	14.548	73.95
14	Sierra Leone	71.7	6.205	86.49
15	Togo	56.8	6.993	123.14
	ECOWAS	**5,112.5**	**336.4**	**65.81**

[11] Source: Commission de la CEDEAO (2012, p. 23).
[12] Source: African Development Bank et al. (2015).

Table 2-6. Demographic indicators of West African countries

	Urban Population (% of total)	Population growth rate (%)		Distribution by age (%)		
				0-14	15-64	65+
	2014	2007	2014	2014		
Benin	46.9	3.1	2.6	42.5	54.6	2.9
Burkina Faso	29.0	2.9	2.8	45.3	52.3	2.4
Cape Verde	64.9	0.4	0.9	28.8	65.9	5.2
Cote d'Ivoire	53.5	1.6	2.4	41.2	55.7	3.2
Gambia	58.9	3.1	3.2	45.8	51.8	2.4
Ghana	53.9	2.6	2.1	38.3	58.3	3.5
Guinea	36.9	2.5	2.5	42.1	54.8	3.1
Guinea-Bissau	46.0	2.2	2.4	41.3	55.8	2.9
Liberia	49.3	4.0	2.4	42.6	54.4	3.0
Mali	36.9	3.2	3.0	47.5	49.8	2.7
Niger	18.6	3.7	3.9	50.1	47.3	2.6
Nigeria	51.5	2.7	2.8	44.4	52.9	2.7
Senegal	43.4	2.7	2.9	43.4	53.6	2.9
Sierra Leone	40.4	2.5	1.8	41.2	56.1	2.7
Togo	39.5	2.6	2.6	41.7	55.5	2.8

Source: African Development Bank et al. (2015)

2.7. Economic profile[13]

2.7.1. Natural and agricultural resources

West African lands favour the production of agricultural resources like cereals, cocoa, coffee, coconut, groundnut, cotton, etc. (cf. Table 2-7). The region is also endowed with a vast wealth of untapped mineral resources, which locally undergo elementary processing (ECOWAS Commission, 2010b) like oil and gas, uranium, gold, etc. (cf. Table 2-8) of which a negligible part is processed by locally implanted industries.

[13] This section is largely based on African Development Bank and African Development Fund (2011).

Table 2-7.Top-10 main agricultural products of West African countries

#	Country	Main agricultural resources
1	Benin	cassava, yams, rice, coarse grain, maize, palm fruit (oil), seed cotton, groundnuts, pulses, sorghum
2	Burkina Faso	rice, sorghum, maize, millet, seed cotton, cow peas, sugar cane, cottonseed, groundnuts, sesame seed
3	Cape Verde	sugar cane, sweet potatoes, potatoes, pulses (nes), coconuts, cassava, maize, coarse grain, rice, oilcrops
4	Cote d'Ivoire	yams, cassava, rice, sugar cane, palm fruit (oil),, maize, seed cotton, cottonseed, coconuts, groundnuts
5	Gambia	rice, groundnuts, millet, palm fruit (oil), maize, sorghum, cassava, pulses (nes), palm kernels, sesame seed
6	Ghana	cassava, yams, rice, palm fruit (oil), maize, taro, groundnuts, coconuts, sorghum, millet
7	Guinea	Rice, cassava, palm fruit (oil), maize, fonio, sugar cane, groundnuts, sweet potatoes, millet, pulses (nes)
8	Guinea Bissau	rice, palm fruit (oil), cassava, groundnuts, coconuts, sorghum, millet, palm kernels, maize, sugar cane
9	Liberia	cassava, sugar cane, rice, palm fruit (oil), taro, sweet potatoes, yams, palm kernels, coconuts, groundnuts
10	Mali	cereals, coarse grain, rice, maize, millet, sorghum, groundnuts, seed cotton, cottonseed, sugar cane
11	Niger	rice, millet, cow peas, sorghum, groundnuts, sugar cane, cassava, potatoes, sweet potatoes, sesame seed
12	Nigeria	cassava, yams, rice, maize, palm fruit (oil), sorghum, sweet potatoes, groundnuts, taro, pulses
13	Senegal	rice, sugar cane, groundnuts, millet, cassava, maize, palm fruit (oil), sorghum, cow peas, sweet potatoes
14	Sierra Leone	cassava, rice, sweet potatoes, palm fruit (oil), groundnuts, sugar cane, pulses (nes), millet, maize, sorghum
15	Togo	rice, cassava, maize, yams, sorghum, beans, palm fruit (oil), seed cotton, palm kernels, groundnuts

Source: FAO Regional Office for Africa (2014)

Table 2-8. Main natural resources of West African countries

#	Country	Renewable natural resources	Non-renewable natural resources
1	Benin	Water, arable land, timber	Small offshore oil deposits, limestone, marble
2	Burkina Faso	Water, arable land	Manganese, limestone, marble; small deposits of gold, antimony, copper, nickel, bauxite, lead, phosphates, zinc, silver, salt.
3	Cape Verde	Water, arable land, fish	Salt, basalt rock, limestone, kaolin, clay, gypsum.
4	Cote d'Ivoire	Water, arable land, Timber, hydro-power	Petroleum, natural gas, diamonds; manganese, iron ore, cobalt, bauxite, copper, gold, nickel, tantalum, silica and sand, clay.
5	Gambia	Arable land, fish	Clay, silica and sand, titanium, tin and zircon.
6	Ghana	Arable land, timber, fish, rubber, hydropower.	Industrial diamonds, bauxite, gold manganese, zinc, nickel, petroleum, silver, salt, limestone.
7	Guinea	Arable land, water, hydropower, fish	Bauxite, iron ore, diamonds, gold, uranium, salt.
8	Guinea Bissau	Arable land, water, fish, timber,	Phosphates, bauxite, unexploited deposits of petroleum, clay, bauxite and limestone.
9	Liberia	Arable land, water, timber	Iron ore, diamonds, gold, hydropower.
10	Mali	Arable land, water, hydropower.	Gold, phosphates, kaolin, salt, limestone, uranium, mineral deposits unexploited: bauxite, iron ore, manganese, tin, and copper.
11	Niger	Arable land, water	Uranium, coal, iron ore, tin, phosphates, gold, petroleum.
12	Nigeria	Water, arable land	Natural gas, petroleum, tin, columbite, iron ore coal, limestone, lead, zinc
13	Senegal	Arable land, water, fish	Phosphates, iron ore.
14	Sierra Leone	Arable land, water, fish	Diamonds, titanium ore, bauxite, iron ore, gold, chromite
15	Togo	Arable land	Phosphates, limestone, marble.

Sources: ECOWAS Commission (2010a) - N'Zué (2014, pp. 4–5)

2.7.2. *Macroeconomic performance*

The Gross Domestic Product (GDP) annual growth rate is comprised between 5 and 7% from 2006 to 2013 at the regional level (Figure 2-2). Agriculture contributes 33%, Industry 36% and Services 31% (Figure 2-3). The growth rate is linked to oil price however (GEA-African studies group et al., 2014, p. 7), because, apart from Nigeria, a big oil producer in the World (and the biggest in the region) and also the major contributor to the regional economic growth (more than 50%, cf. Figure 2-4), some other countries' economy relies mainly on oil production.[14] So the rising prices of minerals and oil, over the last few years the GDP growth rates in the region have been very high and the decreasing price since 2014 would impact the 2014 and 2015 GDP as seen in real GDP and estimates and projection data (Table 2-9). The 2014 Ebola outbreak has also decreased the affected countries' GDP,[15] and hence, that of the region (cf. African Development Bank et al., 2015, pp. 30–31).

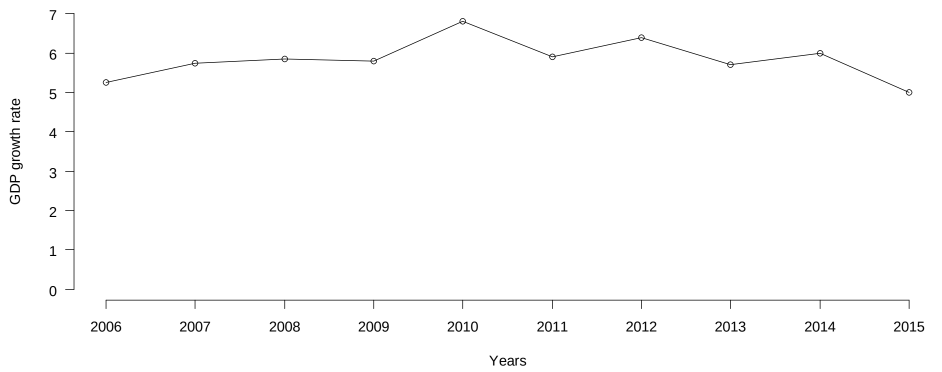

Figure 2-2 West African regional GDP growth rate (2006-2015)
Source: African Development Bank and African Development Fund (2011, p. 4)

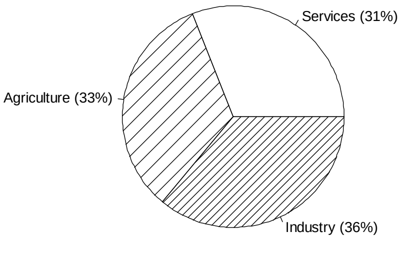

Figure 2-3 Sectorial contribution to West African regional GDP (2010)
Source: African Development Bank and African Development Fund (2011, p. 5)

[14] For instance, in 2012, Niger's GDP increased by 11%, Ghana's by 7.5%, Cote d'Ivoire's by 8.2% and Sierra Leone's by 20% (African Development Bank et al., 2015, p. 31).
[15] "GDP growth in 2014 slowed considerably. Sierra Leone's growth fell from an estimated 13.8% in the African Economic Outlook 2014 to 6%, in Liberia from 6.8% to 1.8%, and in Guinea from 4.2% to 0.6%" (African Development Bank et al., 2015, p. 31).

Table 2-9 West African countries' GDP Growth rate

	2006	2007	2008	2009	2010	2011	2012	2013	2014 (e)	2015 (p)
Benin	3.8	4.6	5.0	2.7	2.6	3.3	5.4	5.6	5.5	5.6
Burkina Faso	6.3	4.1	5.8	2.9	8.4	6.6	9.0	6.6	5.0	5.5
Cape Verde	9.1	9.2	6.7	-1.3	1.5	4.0	1.2	0.7	2.0	3.1
Cote d'Ivoire	0.7	1.6	2.3	3.8	2.4	-4.7	9.8	8.7	8.3	7.9
Gambia	1.1	3.6	5.7	6.4	6.5	-4.3	5.3	4.3	-0.7	4.2
Ghana	6.1	6.5	8.4	4.0	3.4	14.0	9.3	7.3	4.2	3.9
Guinea	2.5	1.8	4.9	-0.3	1.9	3.9	3.8	2.3	0.6	0.9
Guinea-Bissau	2.3	3.2	3.2	3.3	4.4	9.0	-2.2	0.9	2.6	3.9
Liberia	9.1	13.0	6.2	5.4	6.3	7.9	8.3	8.7	1.8	3.8
Mali	5.3	4.3	5.0	4.5	5.8	2.7	0.0	1.7	5.8	5.4
Niger	5.8	3.1	9.6	-0.7	8.4	2.3	11.1	4.1	7.1	6.0
Nigeria	6.0	6.4	6.0	7.0	10.6	4.9	4.3	5.4	6.3	5.0
Senegal	2.5	4.9	3.7	2.4	4.2	1.7	3.4	3.5	4.5	4.6
Sierra Leone	4.2	8.0	5.2	3.2	5.3	6.0	15.2	20.1	6.0	-2.5
Togo	3.9	2.1	2.4	3.4	4.0	4.8	5.8	5.4	5.5	5.7
West Africa	5.25	5.75	5.85	5.80	6.80	5.9,	5.9,6	5.7	6.0	5.0

Source: ECOWAS Commission (2012, p. 36)- African Development Bank et al. (2015)
Note: (e) = estimates – (p) = projections.

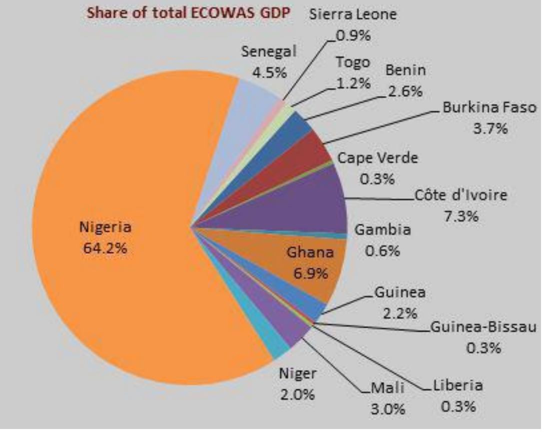

Figure 2-4. West African countries' share to the regional GDP

Source: Minega (2015, p. 34)

2.7.3. Business and competitiveness

The West African private sector is mostly made up of small and medium enterprises. The largest companies are mostly concentrated in Nigeria, and operate mainly in the banking, telecommunications and industrial sectors. 44 of the 50 largest companies in West Africa are also Nigerian. According to the World Bank's *Doing Business 2015*

(World Bank, 2015, p. 4), less than half of the West African countries (7 out of 15) are ranked in the bottom quintile of the 189 countries assessed "on how easy or difficult it is for a local entrepreneur to open and run a small to medium-size business when complying with relevant regulations" (World Bank, 2014a, p. 4). This result is a progress however, compared with the 2010 edition where more than two-thirds (11 out of 15) were ranked in the bottom quintile. Ghana is in the second quintile and the first in the region, followed by Cape Verde and Gambia. Liberia and Guinea Bissau are at the rear (Table 2-10). The ECOWAS has been working towards the harmonization of business laws, including the adoption of a Regional Investment Policy Framework and a Regional Competition Policy.

The Global Competitiveness Index (GCI) has being published annually since 2005 by the World Economy Forum to measure "the microeconomic and macroeconomic foundations of national competitiveness" (Schwab & Sala-i-Martín, 2014, p. 4). In the 2014-2015 report, Ghana is at the top of the ten West African countries included ranked 111th out of the 144 countries; Guinea is at the rear, for both the World and the regional rank (Table 2-11). The 15 ECOWAS countries considered as a whole have an average Corruption Perception Index score of 34, which would rank them 99 out of 167 countries in the third quartile. The best ranked countries are Cape Verde and Ghana and the worst ones are Guinea and Guinea Bissau (Table 2-12).

Table 2-10 Doing business 2015 scores of West African countries

World Rank	Regional rank	Country / Territory	Score
70	1	Ghana	65.24
122	2	Cape Verde	57.94
138	3	Gambia	54.81
140	4	Sierra Leone	54.58
146	5	Mali	52.59
147	6	Côte d´Ivoire	52.26
149	7	Togo	51.29
151	8	Benin	51.10
161	9	Senegal	49.37
167	10	Burkina Faso	48.36
168	11	Niger	47.63
169	12	Guinea	47.42
170	13	Nigeria	47.33
174	14	Liberia	46.61
179	15	Guinea-Bissau	43.21

Source: World Bank (2015, p. 4)

Table 2-11 Global Competitiveness Index 2014-2015 of the West African countries

World Rank	Regional rank	Country / Territory	Score
111	1	Ghana	3.71
112	2	Senegal	3.70
114	3	Cape Verde	3.68
115	4	Côte d´Ivoire	3.67
125	5	Gambia	3.53
127	6	Nigeria	3.44
128	7	Mali	3.43
135	8	Burkina Faso	3.21
138	9	Sierra Leone	3.10
144	10	Guinea	2.79
--	--	Benin	--
--	--	Liberia	--
--	--	Niger	--
--	--	Togo	--
---	--	Guinea-Bissau	--
128		ECOWAS	3.43

Source: Schwab and Sala-i-Martín (2014)

Note: Benin, Liberia, Niger, Togo and Guinea Bissau were not included.

Table 2-12 Corruption scores in West African countries

World Rank	Regional rank	Country / Territory	Score
40	1	Cape Verde	55
56	2	Ghana	47
61	3	Senegal	44
76	4	Burkina Faso	38
83	5	Benin	37
83	6	Liberia	37
95	7	Mali	35
99	8	Niger	34
107	9	Cote d´Ivoire	32
107	10	Togo	32
119	11	Sierra Leone	29
123	12	Gambia	28
136	13	Nigeria	26
139	14	Guinea	25
158	15	Guinea-Bissau	17

Source: Transparency International (2014)

2.7.4. *Infrastructure*

"Logistics is central to daily lives of companies and citizens".[16] West Africa has the lowest quality of transport services, as measured by the Logistics Performance Index compared to both other regions in Africa and the rest of the world (African Development Bank & African Development Fund, 2011, p. 8). In the 2014 Logistics Performance Index (Arvis et al., 2014), West African countries' scores vary from 2.25 to 2.81 ranking them from 75 to 146 out of the 160 countries covered by the report (cf. Table 2-13). Gambia, in the bottom quintile, occupies the worst place and is categorized in the *Logistics unfriendly* economies that includes countries with severe logistics constraints; remaining countries fall under the *Partial performers* category that includes countries with a level of logistics constraints most often seen in low- and middle-income countries. Nigeria, in the fourth quintile, has the best LPI score within the ECOWAS.

In ICT front, there is no coordination activity; however, ECOWAS is addressing the challenge of developing a regional ICT infrastructure through (i) implementation of the INTELCOM II program, including construction of alternative broadband infrastructure, and the laying of submarine cables; and (ii) harmonization of telecommunication/Information and Communication Technologies policies and regulatory frameworks.

The total electricity installed capacity is 12.07 million kilowatts in 2012; the total electricity net consumption is 47.2 billion kilowatt-hours and the total electricity net production is 52.9 billion kilowatt-hours.[17] Of this installed capacity, about 56% is in Nigeria, 17% in Ghana and 13% in Côte d'Ivoire. The West African citizen consummates less than 100 kilowatt-hours a year whereas a Belgium citizen consummates 7,257 kilowatts-hours a year.[18] Apart from Nigeria and Ghana, in the rest of the ECOWAS countries, the cost of electricity is three times what it should be to favour industries contribution to the regional development (ECOWAS Commission, 2010b, p. 24).

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[16] Siim Kallas, former Vice-President of the European Commission and Commissioner of Transport cited by Arvis et al. (2014, p. 5).

[17] Electricity data are taken from United Stated Energy Information Administration (2016).

[18] With its 11.3 million inhabitants (cf. United Nations Population Fund, 2015), that is one thirtieth the population of West Africa, Belgium consummates 82 billion kilowatt-hours in 2012, produced 76.1 billion kilowatt-hours and have an installed capacity of 21 million kilowatts.

Table 2-13. Logistics Performance Index of West African countries

	Score	Rank	Rank (ECOWAS)
Benin	2.56	109	7
Burkina Faso	2.64	98	3
Cape Verde	-	-	-
Cote d'Ivoire	2.76	79	2
Gambia	2.25	146	12
Ghana	2.63	100	4
Guinea	2.46	122	9
Guinea-Bissau	2.43	127	10
Liberia	2.62	102	5
Mali	2.50	119	8
Niger	2.39	130	11
Nigeria	2.81	75	1
Senegal	2.62	101	6
Sierra Leone	-	-	-
Togo	-	-	-

Source: Arvis et al. (2014)

2.8. Social statistics

West Africa is a region which ranks low in the world in all Human Development Indicators. Except Cape Verde and Ghana classified among the middle Human Development Index (HDI), the 13 remaining countries are within the low Human Development group (cf. Table 2-14). 60% of the region's population is estimated to live with less than one dollar a day. Life expectancy at birth in 2015 is 54 years for male and 56 for female (United Nations Population Fund, 2015, p. 127) categorizing the region in the lowest group of the World with the Central African region; just behind Eastern and Southern Africa (58 and 61 years). This data rank West African below the World average of 69 years for male and 74 years for female.

The goal of education for all is not yet attained in West African; indeed, all the children are not enrolled for the primary school. The rate of the population enrolled in the secondary school is lower (cf. Table 2-15). The adult literacy rate ranges from 20 to 70% depending on the country. As the heath sector is concerned, the region has been facing the Ebola outbreak since 2014. The child mortality rate ranges from 26 to 126 for thousand and the under five-years mortality rate is between 35 and 256 for thousand; at the level of the region these two indicators values are 103 and 175 respectively (Organisation Ouest-Africaine de la Santé, 2008, p. 17). The proportion of population using improved sanitation facilities in 2012 is under 50% (World Health Organisation, 2015). The main causes of death and diseases in West Africa are HIV/AIDS, malaria, tuberculosis, meningitis, diarrhea and cholera.

Table 2-14 HDI of West African countries

#	Country	HDI (2014)		
		HDI	Ranking	
			World	Region
1	Benin	0.476	165	5
2	Burkina Faso	0.388	181	13
3	Cape Verde	0.389	123	1
4	Cote d'Ivoire	0.636	171	7
5	Gambia	0.452	172	8
6	Ghana	0.441	138	2
7	Guinea	0.392	179	12
8	Guinea Bissau	0.396	177	11
9	Liberia	0.412	175	9
10	Mali	0.407	176	10
11	Niger	0.337	187	15
12	Nigeria	0.504	152	3
13	Senegal	0.485	163	4
14	Sierra Leone	0.374	183	14
15	Togo	0.473	166	6

Source: UNDP (2014)

Table 2-15. Population at all levels of education in ECOWAS countries (2009 and 2012)

	Primary (%)		Secondary (%)		Tertiary (%)	
	2009	2012	2009	2012	2009	2012
Benin	114.87	122.77	–	54.16^{+1}	9.87	12.37^{-1}
Burkina Faso	77.68	84.96	20.30	25.92	3.53	4.56
Cabo Verde	111.06	111.95	85.27	92.74	15.11	20.61
Côte d'Ivoire	79.57	94.22	–	39.08^{+1}	9.03	4.46
Gambia	85.15^{+1}	85.21	58.84	–	–	–
Ghana	105.53	109.92	58.29	58.19	8.79	12.20
Guinea	84.60	90.83	34.29^{-1}	38.13	9.04	9.93
Guinea-Bissau	116.22^{+1}	–	–	–	–	–
Liberia	99.64	102.38^{-1}	–	45.16^{-1}	9.30^{+1}	11.64
Mali	89.25	88.48	39.61	44.95^{+1}	6.30	7.47
Niger	60.94	71.13	12.12	15.92	1.45	1.75
Nigeria	85.04*	–	38.90*	–	–	–
Senegal	84.56	83.79	36.41^{+1}	41.00^{-1}	8.04	–
Togo	128.23	132.80	43.99^{-1}	54.94^{-1}	9.12+1	10.31

Source: UNESCO (2015, p. 479)

Note

- *estimation by UNESCO Institute for Statistics
- -n/+n = data refer to n years before or after reference year
- More than 100% show higher over rated value than expected ones

2.9. Industry and private sector[19]

The ECOWAS industrial sector is still embryonic and therefore not sufficiently diversified to produce a wide variety of intermediary and finished products. The secondary sector (industry-manufacturing, mining, energy and construction) provides employment for a mere 2 to 10% of the active population according to the country, in 2006; it contributed 30.3% to the GDP with Nigeria in the lead (40.7%) and Gambia (8.9%) and Sierra Leone (8.6%) at the rear. The informal sector absorbs over 60% of the active population in West Africa and produces 20 to 30% of GDP according to the country.

Currently, no ECOWAS country has a robust and solidly productive secondary sector to transform the national economy and join the global competition. The region's share to the global industrial production is less than 0.1%. Over half of the industrial units in West Africa operate at less than 50% of their capacities. The situation varies enormously according to the geographical spheres, which is exacerbated in the landlocked countries (Mali, Burkina Faso, Niger) and those bedevilled by serious power outages (Guinea, Guinea Bissau, Gambia, Sierra Leone and Liberia).

The ECOWAS adopted in 2010 the West African Common Industrial Policy (WACIP) of which the vision is to "maintain a solid industrial structure which is globally competitive, environment-friendly and capable of significantly improving the living standards of the people by 2030" (ECOWAS Commission, 2010a, p. 4). Its general objectives are to i) accelerate the industrialization of West Africa through the promotion of endogenous industrial transformation of local raw materials, ii) develop and diversify the industrial productive capacity, and, iii) strengthen regional integration and the export of manufactured goods (p. 4). The expected results are i) research findings are valorised by the private sector, ii) Industrial activity in the region is re-invigorated and competitiveness strengthened. The key objectives are i) the diversification and widening of the industrial production base, ii) the increasing of the contribution of the industrial sector in the region's GDP from an average of 6-7% to 20% by 2030, iii) considerably improving intracommunity trade from 12% to 40% in 2030, and the exports of manufactured goods from the region to the world market (from 0.1% to 1% in 2030).

The ECOWAS vision 2020 (ECOWAS Commission, 2011b) envisions an ECOWAS of people with a conductive policy environment in which the private sector will be the engine of growth and development, an integrated regional production base developed by competitive private sector activities which provide production and distribution levers for deeper regional integration and development supported by an

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[19] This section is largely based on the West African Common Industrial Policy (ECOWAS Commission, 2010a).

efficient ECOWAS business body that promotes strong public-private partnerships for generating wealth to sustain the development and prosperity of the region.

The main hindrances to the development of the industrial sector in West Africa are related to (African Development Bank, 2011, pp. 3–8; ECOWAS Commission, 2010b): i) strong presence of the informal sector, ii) access to funding for investment in industry, iii) access to efficient technologies (acquisition, maintenance), iv) inadequate national markets, v) low competitiveness of existing industrial capacities and similarity of manufacturing activities, vi) insufficient infrastructures, excessively high costs and/or poor quality of factors of production (electricity, water, etc.) and basic infrastructures (industrial areas, roads, railways, ICT, etc.), vii) underutilization of installed capacities illustrated by the fact that two-thirds of the industries operate at less than 50% of their capacities, vii) bureaucracy and corruption, ix) skill shortages and labour regulations. Consequently to these hindrances, only multinational enterprises operate continuously in the region.

2.10. Higher education

African higher education institutions were inherited from or built on the model of those of the colonial powers. In this sector, education is mainly offered by universities and funded by governments only (African Development Bank, 2008). Through decades, African universities has built solid reputation and followed high international standards. However, with the economic crisis of the 1980s and the implementation of structural adjustment policies which gave priority to basic education, resources to higher education dwindled, resulting in a deterioration of the quality of educational services (African Development Bank, 2008).

The most common model of university in West Africa has been designed under a perspective of 'massification' of teaching and research (Minega, 2015, p. 24). The higher education and research landscape is still characterized by low productivity in terms of support for the regional integration agenda and process, thus its contribution in policy formulation and implementation at national and regional levels remains very marginal. Table 2-16 presents the number of universities and the gross enrolment in percentage of the number of inhabitants of the ECOWAS countries. Nigeria has the larger number of universities, followed by Ghana and Benin; the highest enrolment occurs in Cape-Verde (22.85%) and the lowest in Guinea-Bissau (2.6%).

The higher education in West Africa is facing some challenges. Minega (2015, p. 72) gave the top-ten list of general challenges affecting higher education in Africa (cf. Table 2-17). Particularly, in the case of the West African region, others hindrances i) lack of adequate capacity to contribute effectively to the process of policy development with the objective to enable national governments and Regional Economic Communities to grasp and adopt measures inherent to the implementation of regional integration instruments and frameworks, ii) lack of capacity for mainstreaming the framework on the ECOWAS Policy on Science and Technology at national level, iii) lack of Institutional capacity in the sector, iv) language barrier that affects and handicaps seriously the opportunities for academic cooperation and mobility between institutions across the region; v) unpreparedness for innovation, transformation and internationalization, vi) limited budgets allocated to the education sector by national governments, which are still below the international standards, vii) inadequate institutional capacity and infrastructure, viii) deficit in research capacity, ix) low implementation and harmonization of quality standards, x) insufficient funding and poor environment for social and gender inclusiveness, xi) drain brain and mass exodus of well-trained scholars from the region to first world.

Table 2-16. Higher education institutions and level of enrolment in West African countries

#	Country	Number of universities	Gross enrolment rate (% population)
1	Benin	15	12.50
2	Burkina Faso	4	4.80
3	Cape Verde	5	22.85
4	Cote d'Ivoire	11	9.10
5	Gambia	2	3.42
6	Ghana	48	14.33
7	Guinea	3	10.44
8	Guinea-Bissau	4	2.60
9	Liberia	9	11.64
10	Mali	4	7.50
11	Niger	2	1.80
12	Nigeria	182	10.40
13	Senegal	5	8.04
14	Sierra Leone	4	-
15	Togo	6	10.04
	ECOWAS	304	

Source: Minenga (2015, p. 41)

Table 2-17. Ten Top challenges affecting Higher Education and Research sector in Africa

Rank	Challenges
1	Depreciating quality of higher education teachers
2	Research capacity deficit
3	Infrastructural and facilities inadequacies
4	Lack of a regional quality assurance framework and accreditation system
5	Slow adoption of ICT for delivering quality higher education, including distance education
6	Capacity deficit of quality assurance agencies
7	Weak internationalisation of higher education
8	Management inefficiencies
9	Slow adoption of LMD reforms
10	Poor quality of entrants into higher education from the secondary level

Source: Minega (2015, p. 46)

2.11. Science, technology and innovation

2.11.1. Data on STI in West Africa

Science in Africa is still at its early stage; the entire continent annual scientific output is lower to that of the Netherlands (UNESCO Institute of Statistics, 2005). Table 2-18 gives the scores and ranks of West African countries as regarding technology readiness and innovation according to the Global Competitiveness Report 2014-2015 (Schwab & Sala-i-Martín, 2014). The score of each indicators ranges from 1 one to 7; the more it is close to 7, the best the country performance. West African countries' scores vary from 2 to 4 with an average of the region of 2.8 for Higher education and training, 2.88 for Technology readiness, 2.97 for Innovation, 3.49 for Capacity for innovation, 3.25 for Quality of scientific research institutions, 2.7 for Company spending on R&D, 2.97 for University-Industry collaboration on R&D, etc. The best scores rank the countries in the third quartile over the 144 countries assessed for the competitiveness of their economy.

2.11.2. National policies or strategies

Scientific activities in the West African countries date back to the colonial period where colonial powers were interested in the exploitation of the natural resources their colonies were endowed with (Commission de la CEDEAO, 2012, p. 17; UNESCO, 1986, pp. 14–15). After their independence, the majority of the West African countries incorporated into their socio-economic development plans parts about scientific activities; indeed the governments were fully aware of the important role that science and technology must play in the socio-economic development of their countries (UNESCO, 1974, p. 27, 1986, p. 12). Therefore, no separate policy on science, technology and innovation was formulated at any country level until recent decades. With the efforts of UNESCO (cf. Davis, 1983) in training, advising and technical assistance, either directly with countries or regional organisations (Regional economic community or African Union Commission), African countries have started formulating science, technology and innovation documents. However, some of them still have no sectorial policy.

Statistical data on research in African are scarce, because countries are not used to conduct research and development survey (Mugabe, 2011, p. 7). It is only in recent years that the African Union through the New Partnership for Africa Development (NEPAD) Coordination Agency and the African Observatory on Science, Technology and Innovation have started collecting data on selected countries (African Observatory of Science, Technology and Innovation, 2014; NEPAD Planning and Coordinating Agency, 2014; NEPAD Planning and Coordination Agency, 2010). According to these studies, African countries in general are far from allocating 1% of their GDP to research and development activities whereas South Africa has yet reached 0.96% in 2010 (Blankley & Booyens, 2010) and European Union countries had reached 2% and have targeted 3% in the horizon 2020 (European Commission, 2010a). Table 2-19 gives the Gross Expenditure to Research and Development (GERD) per West African country and Table 2-20 the status of West African countries regarding the adoption of an explicit science policy.

Table 2-18. West African countries' scores and ranks as regarding technology readiness and innovation

	Higher education and training		Technology readiness		Innovation		Capacity for innovation		Quality of scientific research institutions		Company spending on R&D		University-industry collaboration in R&D		Availability of scientists and engineers		PCT patents. applications/ million inhabitants	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Benin	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Burkina Faso	2.4	135	2.5	132	2.9	107	3.4	99	3.4	90	2.3	128	2.2	103	3.5	107	0.0	113
Cape Verde	3.9	99	3.5	80	3.0	101	3.5	97	3.1	108	2.8	107	3.2	97	3.3	112	0.0	124
Cote d'Ivoire	3.1	121	2.8	117	3.3	69	3.5	88	3.9	62	2.2	57	3.3	86	4.2	60	0.0	110
Gambia	3.5	107	3.0	103	3.1	89	3.7	78	3.3	95	2.9	90	3.3	87	3.1	129	0.0	124
Ghana	3.5	106	3.1	100	3.3	63	4.0	49	3.7	73	3.5	44	3.5	77	3.6	95	0.0	108
Guinea	2.2	140	2.4	139	2.2	141	2.7	141	2.3	137	2.0	142	2.2	140	2.9	137	0.0	124
Guinea-Bissau	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Liberia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mali	2.7	128	2.9	112	3.1	92	3.3	112	3.6	79	2.8	99	3.2	100	4.3	50	0.0	124
Niger	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nigeria	2.9	124	3.0	104	2.8	114	3.7	79	2.8	120	2.8	106	2.8	123	3.8	99	0.0	117
Senegal	3.2	119	3.2	96	3.4	57	3.9	56	3.9	66	3.2	58	3.6	65	4.1	68	0.1	104
Sierra Leone	2.4	137	2.4	138	2.6	130	3.2	117	2.5	133	2.5	124	2.4	134	3.0	134	0.0	111
Togo	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
ECOWAS (Average)	2.98		2.88		2.97		3.49		3.25		2.7		2.97		3.58		0.01	

Source: Schwab and Sala-i-Martín (2014)

Note: Benin, Liberia, Niger, Togo and Guinea Bissau were not included.

Table 2-19. GERD and researchers in the West African countries

#	Country	GERD (% GDP)	Researchers[20] (2007)	Researcher / million inhabitant (2007)[20]
1	Benin	--	1,000	119
2	Burkina Faso	0.2[21] (2009)	742 (2010)	42
3	Cape Verde	0.07[21] (2011)	25 (2011)	51
4	Cote d'Ivoire	--	1,269	66
5	Gambia	0.13[21] (2011)	46	30
6	Ghana	0.38[22] (2010)	941[23]	39[23]
7	Guinea	--	2117	253
8	Guinea Bissau	--	--	--
9	Liberia	--	--	--
10	Mali	0.66[21] (2010)	513	42
11	Niger	--	101	8
12	Nigeria	0.22[21] (2007)	28,533	203
13	Senegal	0.54[21] (2010)	3,277	276
14	Sierra Leone	--	-	-
15	Togo	0.22[21] (2012)	216	34

2.11.3. Regional policy and strategies

At the African continent level, African Union Member States have renewed in several documents their commitment to give priority to science, technology and innovation to solve the problems the African peoples are facing. In 2007, the ECOWAS Commission created within the Office of the Commissioner in charge of Human Development and Gender, a Department for Education, Culture, Science and Technology with a mandate to promote science, technology and innovation for regional integration, economic development, overall poverty reduction and social emancipation of the people of West Africa.[24] The ECOWAS vision 2020 (ECOWAS Commission, 2011b) reaffirms the necessity to promote active participation of the academic community in all issues relating to the integration process.

The first Conference of the ECOWAS ministers of Science and Technology met in 2004. In 2005, the Conference elaborated a framework basis for science and technology (Commission de la CEDEAO, 2012). The conference recommended the establishment of a community sectorial policy of which the objective should be to incite scientists and researchers to study the issues the ECOWAS peoples were facing and to bring solutions. The ECOWAS Policy on Science and Technology (ECOPOST)

[20] Source: UNESCO (2010b, p. 284) otherwise specified.
[21] Source: UNESCO (2015, p. 481)
[22] Source: NEPAD Planning and Coordination Agency (2010, p. 37) for the year 2007/2008.
[23] Source: NEPAD Planning and Coordination Agency (2010, p. 43).
[24] http://www.comm.ecowas.int/dept/stand.php?id=e_e1_brief&lang=en

and its action plan (Commission de la CEDEAO, 2012) were adopted by the Authority of Heads of State and Government on 29 June 2012 (CEDEAO, 2012). The ECOPOST addresses 12 thematic areas: (a) scientific research, innovation and technological development; (b) support for education and training; (c) higher education; (d) scientific culture; (e) enabling environment for scientific creativity; (f) regional and international cooperation; (g) capacity building; (h) science and technology and private sector involvement; (i) information on science and technology: data, statistics and indicators; (j) gender, science and technology; (k) E-governance and Internet massification; and (l) transfer of technology and technology watch (United Nations Economic Commission for Africa, 2013, p. 79).

2.11.4. Problems of STI in West Africa

The NEPAD Planning and Coordination Agency (2014, p. 15) noticed that common themes emerge from STI policy and strategy frameworks in African countries; they relate to capacity for science, technology and innovation, human resource development, promoting and funding research and development, and STI policy and measurements. This conclusion illustrates that the African national innovation systems in general and the West African ones in particular have common hindrances. These include (cf. Commission de la CEDEAO, 2012, p. 3; Mêgnigbêto, 2013e; Minega, 2015; UNESCO, 1986, p. 19, 2010b, pp. 282–285, 2015; United Nations Economic Commission for Africa, 2013, p. xviii): i) insufficient funding and equipment, ii) lack of motivation of personnel, iii) lack of explicit science, technology and innovation policy in some countries, iv) inexistence of a regional database on publications, vi) lack of well-informed and organized policy research institutions and advisory bodies to help identify key priority areas where countries may invest their limited resources and set clear and measurable targets, vii) lack of dynamism in STI policies policy design, development and implementation, viii) lack of assessments, monitoring and evaluation of the impact of policy actions, iv) lack or absence of interactions between innovation actors, and, x) non-involvement of universities and research centres to the establishment of STI policy, plan or strategies.

Table 2-20. Status of West African countries regarding the existence of an explicit STI policy

#	Country	Existence of a STI policy	Year of the adoption of the first STI policy	Year of the adoption of the current STI policy	Number of STI policies yet formulated
1	Benin	Yes	2006	2015[25]	2
2	Burkina Faso	Yes	1995[26]	2012[27]	2
3	Cape Verde	No	-	-	-
4	Cote d'Ivoire	No[28]	-	-	-
5	Gambia	Yes[29]	-	2013	1
6	Ghana	Yes	2000[30]	2010	2
7	Guinea	No	-	-	-
8	Guinea Bissau	No	-	-	-
9	Liberia	No[31]	-	-	-
10	Mali	Yes[31]	2009	-	-
11	Niger	Yes	-	2013[32]	1
12	Nigeria	Yes	-	2011	1
13	Senegal	No	-	-	-
14	Sierra Leone	No	-	-	-
15	Togo	Yes[33]	-	2014	1

[25] The new policy is still under development in 2015 (UNESCO, 2015, p. 482).
[26] http://fr.allafrica.com/stories/201207100634.html
[27] Source: Buclet and Essayie (2013, p. 16); UNESCO (2015, p. 483).
[28] cf. UNESCO (2015, p. 487).
[29] cf. UNESCO (2015, p. 488).
[30] Ghana. Ministry of environment, science and technology (2010, pp. 1–5).
[31] cf. UNESCO (2015, p. 491).
[32] Approved by the government but still waiting adoption by the Parliament (UNESCO, 2015, p. 492
[33] cf. UNESCO (2015, p. 495).

2.12. Conclusion

West Africa groups together 15 countries out of 54 the African continent counts. It coincides with the Economic Community of the West African States (ECOWAS) created in 1975. ECOWAS countries are commonly classified among the low income countries in the world and are characterized by an uneven economic development. As a regional integration area, the ECOWAS has achieved some progresses namely customs union, free movement of persons, ECOWAS passport (African Development Bank & African Development Fund, 2011, p. iv) that make it the most integrated regional economic community in Africa (Page, Bilal, & Overseas Development Institute, 2001, p. 1; Sesay & Omotosho, 2011, p. 21) and one of the most successful integration arrangements to date, following closely behind the European Union (ECOWAS Commission, 2011a, p. 12). The region covers more than five million square kilometres and counts more than 300 million inhabitants. Its Member States are among the poorest of the World. Up to 1990, almost all the Member States were ruled by a totalitarian regime with regular coup d'états; since then, they all have recognized democracy as a condition for development. However, the region is still facing severe political and security issues.

West African countries are endowed with some natural resources; but industrialisation is at its beginning. Even the installed industries are facing some problems hindering there development.

Both national and regional authorities are aware of the role of Science, Technology and Innovation in the development of the Member States and region. In the earlier years of independence, they had formulated development plans that all emphasised the role of Science, Technology and Innovation. Some countries established policies of Science, Technology and Innovation. But they all are struggling in funding their research institutions and activities. So, globally the region is still depending on Western countries, namely former colonial powers. Science, Technology and Innovation are hampered by so many factors that UNESCO (2010b, p. 281) could affirm that "sub-Saharan Africa still has a long way to go to reach the eldorado of the knowledge economy, not only in terms of innovation but also as regards the other three pillars of the knowledge economy: a sound economy and institutional regime; an educated, creative population capable of utilizing knowledge effectively; and a dynamic information infrastructure".

3. An overview of the West African scientific profile

In this chapter, we draw the landscape of research activities in the West African region and compared the region's scientific performance to that of Brazil, Russia, India, China and South Africa (referred to as BRICS) over a ten-year period (2001-2010). Analyses focused on total output, international collaboration rate, main partner countries, citable documents and h-index.

This chapter is the development of the content of a poster presented at the 13th Science and technology indicator (STI 2013) held in Berlin, Germany, 3-5 September 2013 (Mêgnigbêto, 2013d) and a brief communication published in the ISSI Newsletter (Mêgnigbêto, 2013f).

3.1. Introduction

West Africa is one of the five African regions as determined by the African Union.[34] It counts 15 countries; in the alphabetic order, they are: Benin, Burkina Faso, Cote d'Ivoire, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Nigeria, Niger, Senegal, Sierra Leone and Togo. Three international languages (French, English and Portuguese) are distinguished in the region as the legacy of the colonisation by France, United Kingdom and Portugal. All the West African countries are together member of the Economic Community of West African States (ECOWAS), a regional economic integration organisation. In early 2012, the region adopted the ECOWAS Policy on Science and Technology (ECOPOST) that recognized the role of Science, Technology and Innovation in regional integration and life conditions improvement.

Scientometric studies on the whole or part of Africa are very limited, compared to other continents, even though an evident interest has been registered recently (Adams et al., 2010; Boshoff, 2009, 2010; Mêgnigbêto, 2013a, 2013e; NEPAD Planning and Coordination Agency, 2010; Onyancha & Maluleka, 2011b; Tijssen, 2007; Toivanen & Ponomariov, 2011). They found that i) Africa's share to the world output is very negligible, ii) the big science producers in Africa are Egypt in the North, South Africa in the South, Kenya in the East and Nigeria in the West; iii) the big producers also drive collaboration links; therefore, they are the backbone of the scientific collaboration network in Africa and connect African regions and Africa to the world; iv) language, culture, colonial ties and geographical proximity are criteria for collaboration; v) hence, the main African countries' common partners are former colonisers, namely France and United Kingdom; however, USA follows as the third common partner country even though it has no former colony on the Continent; vi) collaboration between African countries is weak; and vii) developed countries are the major non-African partners of African countries.

[34] Resolution CM/Res.464 (XXVI) adopted by the African Unity Organization (now African Union) Council of Ministers meeting in its twenty sixth ordinary session in Addis-Ababa (Ethiopia) from 23 February to 1st March 1976. The countries list was updated in 2004.

Some regions or countries, like the South African Development Community (SADC) and South Africa, have been steadily explored; others lack examination. In this chapter, we intend to give a view of the West African research landscape on the eve of the ECOPOST adoption. The research question is: How does West Africa compare to emergent countries like Brazil, Russia, India, China and South Africa with respect to scientific publishing?

3.2. Methods and data

In April 2012, we performed a search on Web of Science; we retrieved all the publications co-authored by at least one scientist from any West African country. The databases selected were Science *Citation Index Expanded (SCI-EXPANDED)*, *Conference Proceedings Citation Index- Science (CPCI-S)*, *Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH)* and *Index Chemicus (IC)*. All languages and all document types were checked. The exact search expression entered into the advanced search form was *cu=benin or cu=burkina faso or cu=cote ivoire or cu=cape verde or cu=gambia cu=ghana or cu=guinea or cu=guinea-bissau or cu=liberia or cu=mali or cu=niger or cu=nigeria or cu=senegal or cu=sierra leone or cu=togo*. From the results, 28,380 records related to the period 2001-2010 (a 10-year period) were extracted, downloaded and imported into a bibliographic database managed with CDS/ISIS[35] thanks to a program coded into CDS/ISIS Pascal.[36] The defined fields in the CDS/ISIS database were based on the bibliographic information from Web of Science data, as follows: authors, title, source title, year of publication, times cited, language, type of document, (co-) authors' affiliation (addresses), etc. Searches related to each country of BRICS were performed separately (cu=brazil, cu=Russia, cu=india, cu=china, cu=south africa) in November 2012 and the *Analyse Results* function of Web of Science was used. Thanks to the CDS/ISIS formatting language[37] and search function, West African data were printed into a file and analysed with statistical software or computed directly.

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[35] CDS-ISIS is text database management software developed and distributed by UNESCO (UNESCO, 1989a). (http://www.unesco.org/isis).

[36] CDS/ISIS provides a programming language ''designed to develop CDS/ISIS applications requiring functions which are not readily available in the standard package'' (UNESCO, 1989b). This programming language enables users to extend functions of the standard package, to make it more robust and in order to meet users' specific needs (Mêgnigbêto, 1998).

[37] «The formatting language allows you to define precise formatting requirement for data base records. Through this language, you may select one or more specific data elements in the order you want and optionally insert constant text of your choice, e. g. to label some or all the fields, as well as specify vertical or horizontal spacing requirements (…). The formatting language is therefore the core of many operations and an efficient use of CDS/ISIS requires a thorough knowledge of this techniques» (UNESCO, 1989a).

3.3. Results

3.3.1. Annual production

The total number of bibliographic references considered in this chapter is 28,380. The West African Member States' share to the regional scientific output is represented in Table 3-1. It reveals that, on its own, Nigeria produced more than half the total output of the region, far followed by Ghana (11.29%), Senegal (8.96%), Burkina Faso (6.29%) and Cote d'Ivoire (5.88%). The remaining 10 countries output each less than 5% of the region's total scientific papers. These statistics illustrate a very skewed distribution (Gini index = 0.708); as an illustration, the top-three producers published 7 papers out of 10. Nigeria appears to be the biggest science producer in West Africa; factors like the economic performance and the size of the population might have favoured these ranking. The annual production curve is best fitted by a linear trend of which equation is $y = 361.45t + 850$ where y is the number of papers and t the period of time (t = 1 in 2001 and $r^2 = 0.96$). Figure 3-1 shows West Africa's output curve, its linear fit, the region except Nigeria output and the Nigerian annual production curve.

From 2001 to 2005, Nigeria produced about half of the total production of the region; however, starting from 2005, its production rose slowly and separated from the production curve of the rest of the region; the demarcation between the two curves became more pronounced in 2006. From then on, Nigeria scientific output became larger; that is, since 2006, Nigeria's annual production has exceeded that of the other 14 countries of West Africa grouped together.

Table 3-1. Scientific output of West African countries

Rank	Country	Publications share	
		Papers	Percentage
1	Nigeria	15,569	54.86
2	Ghana	3,203	11.29
3	Senegal	2,544	8.96
4	Burkina Faso	1,785	6.29
5	Cote d'Ivoire	1,669	5.88
6	Benin	1,335	4.70
7	Mali	1,204	4.24
8	Gambia	986	3.47
9	Niger	586	2.06
10	Togo	433	1.53
11	Guinea	241	0.85
12	Guinea Bissau	225	0.79
13	Sierra Leone	117	0.41
14	Cape Verde	52	0.18
15	Liberia	49	0.17

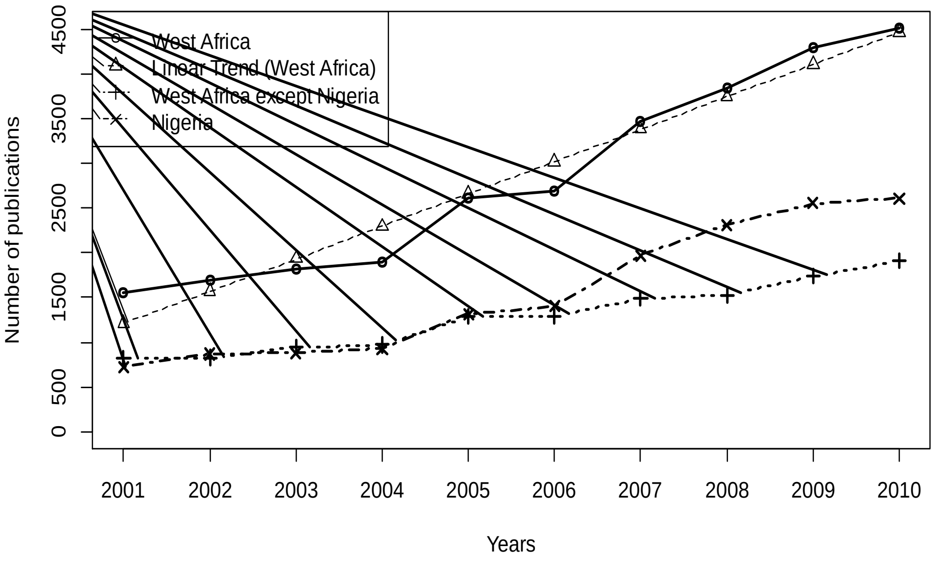


Figure 3-1 Annual scientific production in West Africa

3.3.2. Languages, types of publication and cited documents

The West African publications are written in English mainly (95.5%); French papers come far behind (4.35%); other languages (total less than 0.07%) are German, Japanese, Portuguese, Romanian, and Spanish. The data source may have influenced these statistics, indeed, Web of Science is known to include relatively few non-English publication outlets. Almost all the publications (94%) are citable. The annual rate of cited documents reported to the total of citable documents progressively decreased from 81% in 2001 to 45% in 2010 following an exponential negative trend; indeed, recent papers have been less cited. The average ratio of cited publications over the period is 63.99%; that is, 36.01% of the publications have received no citation (Table 3-2). The cited documents received an average of 10.39 citations; the median citation is 4, that is 50% of the cited documents received up to 4 citations each and the second half received at least four citations (Figure 3-3). The breakdown of the publications per document type gives: Article 76.67%, Meeting Abstract 10.88%, Article-Proceedings Paper 2.57%, Letter 2.17%, Review 2.33% and Note 0.14%.

The h-index was proposed by Hirsch (2005) originally to evaluate an individual scientist's performance. It has been used widely; it was extended and could also apply to institutions countries, groups of countries, or any information producer (Liu, 2011; Persson, 2013) even it is also criticised for not being suitable for comparison purpose (Leeuwen, 2008; Waltman & van Eck, 2012). To compute the h-index of West Africa, from the CDS/ISIS database, we printed into a file the times each document is cited (field “times cited”), each value on a new line. This file was then sorted in descending order and its lines numbered. The h-index is the largest number h such that the first h documents are each cited at least h times. In the case of West African data, we found that h-index equals 100.

Table 3-2. Repartition of papers per number of citations received.

Range of citations	0	1 10	11-50	51-100	101-200	201-500	> 501	Total
# papers	10,221	13,624	4,097	339	74	18	7	28,380
% papers	36.01	48.01	14.44	1.19	0.26	0.06	0.02	100

3.3.3. Production per field

Web of Science is used to classify bibliographic records according to its own knowledge field scheme structured in two levels. The first level counts 5 categories; the second level gives subject areas (approximately 200) that are added to bibliographic records. The revised version of the Frascati Manual Fields of Science (OECD, 2007) was used to categorize publications considered in this study. Based on the concordance table provided by Thomson Reuters (2010), combined searches were performed over the CDS/ISIS database and the field shares computed. The region produced mainly in *Medical and health sciences* (49%), followed by *Natural sciences* (32.81%), *Agricultural sciences* and *Engineering and technology* have approximately the same score (around 13%) (Figure 3-2). It should be underlined that the Web of Science’s databases we used for data collection include neither the Social Science Citation Index (SSCI nor the Art and Humanities Citations Index (A&HCI), so the scientific performance of the region presented is more an effect of the data source than the actual situation.

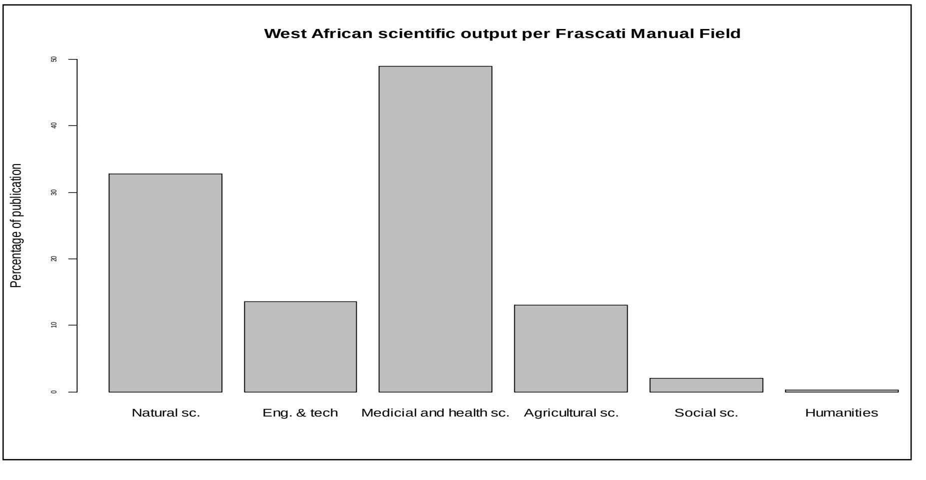
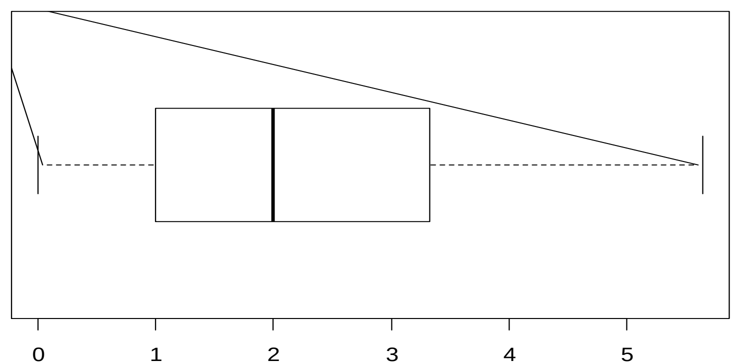
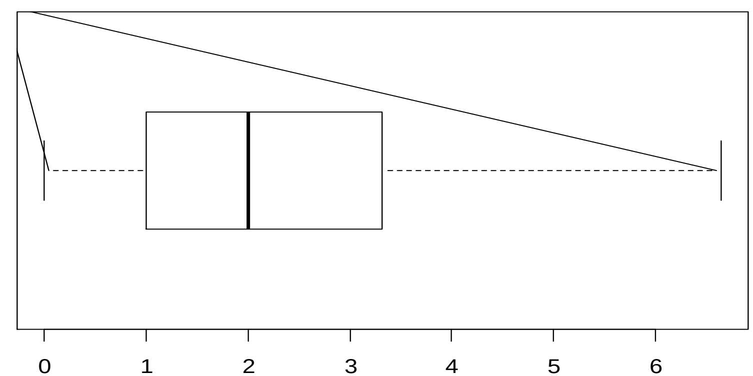


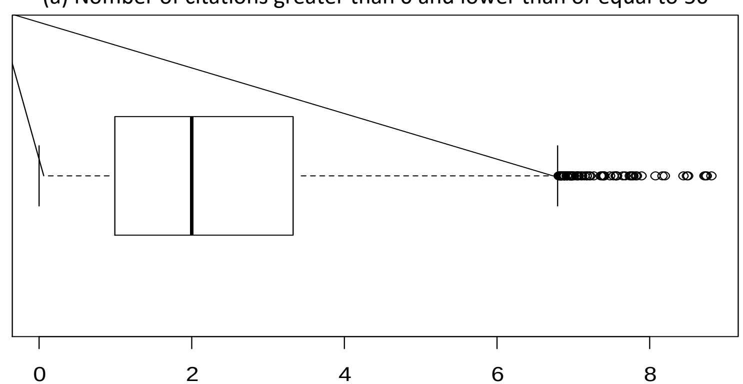
Figure 3-2 West African scientific output per Frascati Manual Fields of Science



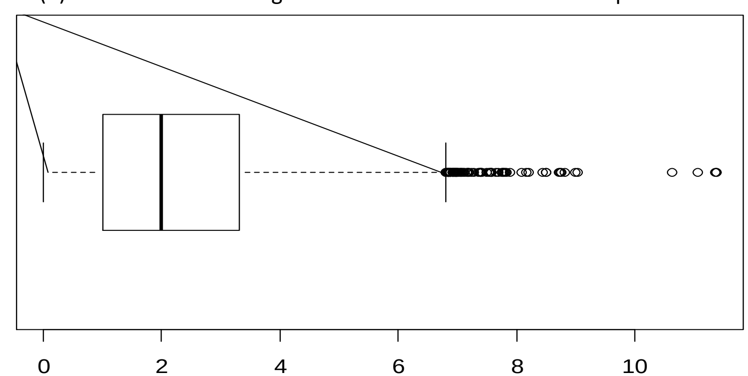
(a) Nomber of citations greater than 0 and lower than or equal to 50



(b) Nomber of citations greater than 0 and lower than or equal to 100



(c) Nomber of citations greater than 0 and lower than or equal to 500



(d) All cited papers

Figure 3-3. Boxes-plot of the West African scientific output

Note : Logarithmic scale (base 2) was used for the number of citations

3.3.4. Research institutions

Globally, 4,622 institutions contributed to the West African scientific research over the period 2001-2010. It is meaningless to give a top list of them. Furthermore, often, affiliations in bibliographic data contain errors so that the same author or institution may appear in many forms (Bruin & Moed, 1990; Moed, 1988). Therefore, there is a need to normalise. Browsing a list of 4,622 institutions names for this purpose is a huge work. Besides, research is primarily university's mission; for social and economic development, research products need to be transformed by industry into products, services and processes useful for society; these two entities need a regulatory framework set up by the government. The collaboration between the three actors (University, Industry and Government) creates the knowledge infrastructure necessary to a knowledge-based economy (Leydesdorff, 2003; Leydesdorff & Meyer, 2006). It ensures innovation (Etzkowitz & Leydesdorff, 1995, 2000). Therefore, we opted to categorize authors' addresses according to these actors, i.e. 'University', 'Industry' and 'Government'; thus, we used the search string proposed and tested by Leydesdorff (2003) to label authors' addresses. We found that University authored 82.82% of papers, Government 41.09%, Industry 1.07%; research institutions that didn't fall under the above categories include NGOs, private and international account for 3.80%. If we restricted to West African-based institutions, University produces 67.45% of papers, Industry 0.33%, Government 26.89% and 'not classified' institutions 11.46%.

3.3.5. Co-authorship

We computed the number of papers in the West African scientific output according to the number of authors they have. We distinguished from 1 to 5 authors and 6 and more authors. The curves are shown in Figure 3-4. For the clearness of the figure, trends were not plotted. It is clear that the increasing rate is the highest in case of papers with 6 and more authors. Besides, Table 3-3 shows that the total number of co-authors per year rose from 6,759 in 2001 to 23,608 in 2010. Conversely, the number of papers per co-author trended downward, from 0.23 at the beginning of the period to 0.19 at the end. The same trends are registered about cumulative data (Table 3-4). Overall, there are 136,961 co-authorships for 28,380 papers; the subsequent ratios are: i) number of co-authors per paper: 4.82, ii) number of papers per author 0.21. Two possible explanations for this trend in co-authorship are: i) the fields involved: the sciences are more inclined to co-authorship (Ossenblok et al., 2012, 2014); furthermore, social sciences and humanities are not covered by the Web of Science databases data were collected from, and ii) international collaboration: almost half of West African output depends on international collaboration. Hence, there is automatically a preference for larger collaborations.

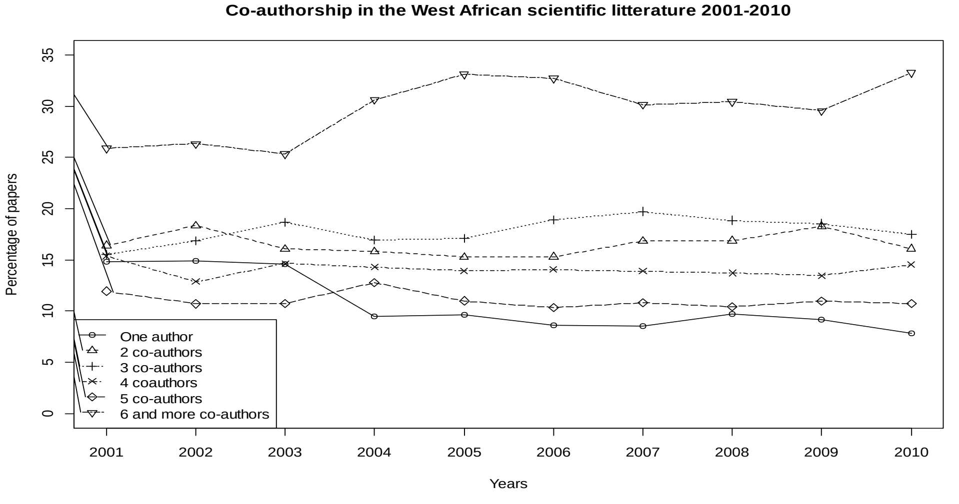


Figure 3-4 . Co-authorship in the West African scientific literature

3.3.6. *International collaboration*

14,094 papers accounting for 49.66% of the West African total output have at least one non-West African address. The lowest international collaboration rate (45.26%) was registered in 2008 and the highest (56.44%) in 2004. An increasing trend is registered until 2004 followed by a decreasing trend between 2004 and 2009. The region's collaborators count 151 countries among them 38 African, 27 American, 40 Asian, 41 European and 5 Oceanian. France is ranked first; it contributed to the West African scientific literature with 3,572 papers accounting for 12.59% of the region's output; this number also represents about one quarter of the total papers West Africa shared. Just behind, follows the USA as second partner, with 12.54%, followed by the United Kingdom (10.09%). The fourth partner is Germany, far behind with 4.39%. South Africa is ranked fifth and the first African country with 3%.

Europe is by far the first partner of West Africa with 27.12% (9,655 papers) of contributions followed by America 14.55% (4,240 papers), Africa 8.79% (2,530 papers), Asia 5.29% (1,540 papers) and Oceania 1.29% (367 papers). At the European Continent level, France and the United Kingdom are respectively first and second partner countries with 37% and 29.65% of the papers with a European address. In America, the USA on its own contributed to more than 4 papers out of 5 the continent shares with West Africa. Globally, these 3 countries, with 8,920 papers accounting for 31.43% of the West African total output and 63.28 % of the papers with a non-West African address, are the main partners of West Africa.

Table 3-3 Co-authorship, number of papers per co-author and number of author per paper

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Number of co-authorship	6,759	7,378	7,858	8,963	12,758	13,437	16,525	18,647	20,758	23,608	136,691
Number of papers	1,548	1,701	1,825	1,901	2,608	2,693	3,464	3,836	4,293	4,511	28,380
Average number of authors per paper	4.370	4.340	4.310	4.710	4.890	4.990	4.770	4.860	4.840	5.230	4.820
Average number of paper per author	0.230	0.230	0.230	0.210	0.200	0.200	0.210	0.210	0.210	0.190	0.210

Table 3-4 Cumulative co-authorship, number of papers per co-author and number of authors per paper

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Number of co-authorship	6,759	14,137	21,995	30,958	43,716	57,153	73,678	92,325	113,083	136,691	136,691
Number of papers	1,548	3,249	5,074	6,975	9,583	12,276	15,740	19,576	23,869	28,380	28,380
Average number of authors per paper	4.370	4.351	4.335	4.438	4.562	4.656	4.681	4.716	4.738	4.816	4.820
Average number of papers per author	0.230	0.230	0.231	0-.225	0.219	0.215	0.214	0.212	0.211	0.208	0.210

3.3.7. *Comparison with BRICS countries*

BRICS is the acronym for the grouping of the world's leading emerging economies, namely Brazil, Russia, India, China and South Africa (Arkhangelskaya, 2011). The members of the BRICS, excepted Russia, are newly industrialized; some decades ago they had the same economic and social conditions as compared to West Africa. We chose to compare West Africa, a region grouping 15 countries, to individual BRICS countries for four main reasons: i) individual West African Member States scientific output are too negligible to allow for comparison with BRICS individual countries; ii) even the whole region scientific output is still too low to allow for comparison with a region or a group of countries; iii) the whole of Africa's science output is comparable to that of an European country like The Netherlands (Adams et al., 2010); and iv) the BRICS countries are viewed as models for other developing countries in science and technology (Adams et al., 2013).

The comparison is done with respect to selected indicators like total output, annual output, percentage of citable documents, international collaboration rate and partner countries. Even though Nigeria, one of the bigger African science producers (Adams et al., 2010; Dahoun, 1999) is a West African country, the whole region performs less than Brazil, Russia, India, China and South Africa, the leader in science producing on the African continent. Indeed, over the same period of time, Brazil produced tenfold the West African volume of papers (63,046), Russia and India about twelvefold, China about fiftyfold, and South Africa over twofold (Figure 3-5 and Table 3-5). Approximately 43% of South African papers have at least one foreign address; Brazil, Russia, India, and China share less than one third of their scientific output; hence, West Africa depends more on international collaboration than the four countries.

The top 5 partner countries list of West Africa and the BRICS countries exhibits USA, UK and Germany as common partners. USA is the first partner of Brazil, India, China and South Africa, but second of West Africa and Russia; France, the first West African partner is ranked second in case of Brazil, third in case of Russia and fifth in case of India and South Africa (Table 3-6). Globally, compared to BRICS countries, West Africa has the lowest total output, the lowest citable percentage share; on the other hand, it has the highest international collaboration rate, which means that West Africa produced less than each BRICS country, that its scientific production counts less citable papers, that its research quality measured by the number of citation is poorer than that of each BRICS countries and finally that the region depends more on international collaboration than BRICS countries.

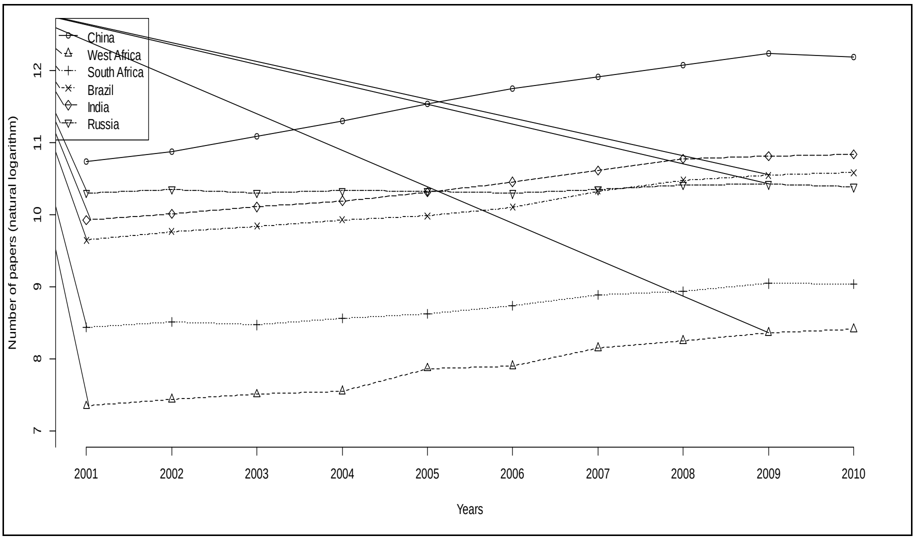


Figure 3-5 Comparison of West African and BRICS Comparison of West African and BRICS countries' scientific output

Note: Because of the scale between the outputs of China and West Africa (the biggest and the smallest science producers, respectively, within the set of considered countries), we use the logarithm of the countries’ annual output to allow for plotting data on the same figure.

Table 3-5 Comparing West Africa to China, India, Brazil and South Africa (total output and international collaboration)

Country/region	Total output (2001-2010)	International collaboration (%)
West Africa (WA)	28,380	49.66
Brazil (BR)	261,876	25.12
Russia (RU)	307,915	30.81
India (IN)	346,992	17.56
China (CN)	1,199,239	16.27
South Africa (SA)	63,087	43.38
Comparison	WA < SA < BR < IN < RU < CN	CN < IN < BR < RU < SA < WA

Table 3-6. Partner countries' share (in percentage) and rank in West Africa and BRICS countries' scientific output

Partner country	West Africa		Brazil		Russia		India		China		South Africa	
	Rank	Share	Rank	Share	Rank	Share	Rank	Share	Rank	Share	Rank	Share
Australia	-	-	-	-	-	-	-	-	-	-	4	4.17
Canada	-	-	-	-	-	-	-	-	5	1.22	-	-
France	1	12.59	2	3.18	3	4.37	5	1.4	-		5	3.84
Germany	4	4.39	3	2.77	1	8.46	2	2.41	3	1.38	3	5.35
Italy	-	-	-	-	5	2.79	-	-	-	-	-	-
Japan	-	-	-	-	-	-	4	1.66	2	2.15	-	-
South Africa	5	2.99	-	-	-	-	-	-	-	-	-	-
Spain	-	-	5	1.82	-	-	-	-	-	-	-	-
UK	3	10.09	4	2.6	4	2.97	3	1.76	4	1.35	2	9.12
USA	2	12.54	1	10	2	7.99	1	6.06	1	6.62	1	14.52

3.4. Discussion

West Africa shared approximately one half its annual production; this rate is higher than that of individual BRICS countries. Europe and America are the main partners at continent level. This finding confirms the result of many previous studies (e.g. Adams et al., 2010; Boshoff, 2009; Tijssen, 2007; Toivanen & Ponomariov, 2011). If colonial ties explained the ranking of France and the United Kingdom (Boshoff, 2009), Adam et al. (2010) justified the presence of the USA, a country with no former colonies in the region: "Often this is a consequence of researchers who have studied in the USA and maintaining links with USA-based research groups once they returned home". The argument might also apply to Belgium and Germany. As an illustration, Australia, Canada, Italy, Japan and Spain that are among individual BRICS countries top five partners didn't appear in the West African list. West Africa and BRICS shared three countries as top-5 partners; they are USA, UK and Germany. But West Africa depends much more on them than BRICS countries (35% against 30% for South Africa and 10 to 15% for Brazil, Russia, India and China).

Table 3-7 gives some social, economic and research statistics (scientific output, population, scientific population ratio, GDP, GERD and HDI[38]) of the region and BRICS countries. Even though China and India are ranked first and second respectively regarding total output, they take fifth and fourth position respectively, behind Russia (1st), Brazil (2nd) and South Africa (3rd) while output is reported to population size; West Africa is at the rear. The region has the highest poor population share (60% against 3.8 to 40% for BRICS countries); its GDP is the lowest. Among the fifteen West African Member States, thirteen were categorized within Low HDI; only two belong to the middle HDI group (Cape Verde and Ghana, HDI > 0.536).The region's HDI (the average of the fifteen Member States) categorize the region in Low HDI; whereas BRICS countries have an HDI ranging from 0.554 to 0.730. It meant that the region's welfare measured by the HDI is lower than that of the individual BRICS countries. Besides, whereas West Africa devotes 0.215% of its GDP to research funding, BRICS countries allot 0.87 to 1.76%, that is four to eight times the West African GERD. Furthermore, West Africa counts 60% of its population among poor people. In conclusion, the region is facing social and economic difficulties that make it could not prioritize research funding. Therefore, the investment in research and development is weak. Boshoff (2009) underlined that Sub-Saharan Africa's countries "are struggling to reach the target of allocating at least 1% of GDP to R & D" as they committed in the Lagos Action Plan (Organization of African Unity, 1980).

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[38] GDP, GERD and HDI are not available at West African region level; therefore, for the region, we took the average of member countries, in order to enable comparison with BRICS countries.

Table 3-7. Social and economic and research data for West Africa and BRICS countries

Country/Region	Output	Population 2012 (× 1,000)	Output / population (× 1,000)	HDI (2013)	GDP per capita 2012 (USD)	GERD(2005-2010)	Poverty (% population)
West Africa	28,380	318,700	0.089	0.421	981.2	0.215	60.0
Brazil	261,876	198,700	1.318	0.730	12,594	1.16	3.8
Russia	307,915	143,500	2.146	0.788	14,037	1.16	-
India	346,992	1,236,700	0.281	0.554	1,489	0.76	41.6
China	1,199,239	1,350,700	0.888	0.699	5,445	1.76	15.9
South Africa	63,087	51,200	1.232	0.629	8,070	0.87	17.4

Sources : World Bank (2014b) - UNDP (2013) – ECOWAS Executive Secretary and WAEMU Commission (2006)

3.5. Conclusion

The West African scientific output over the period 2001-2010 were studied and compared to that of BRICS countries. The region's annual output is increasing linearly. Nigeria, the largest country of the region and also one of the bigger African science producers, on its own outputs half of the West African total production. Medicine and health sciences and Natural sciences are the main fields the West African countries produce in. The West African scientific profile was compared to that of Brazil, Russia, India, China and South Africa (known under the acronym BRICS). The selected indicators for comparison are the total output, the percentage of citable documents and the share of international collaboration. We found that West Africa performs less than BRICS countries taken individually. With respect to the total scientific production over the period 2001-2010, West Africa occupies the last position; With regard to the percentage of citable documents, the region is ranked behind South Africa, India, Brazil and China, but in front of Russia; West Africa depends more on international collaboration because it has the highest international collaboration rate. BRICS countries and West Africa share three partners among the top five, namely USA, UK and Germany. However, West Africa depends more in this three countries than the others. Even though scientific output reported to total population size is considered, West Africa still at the rear. This position of West Africa regarding its scientific output is due to the difficulties science in the region is facing. Mêgnigbêto (2013e) gave some of them that are (i) lack of coordination between research programs and research activities, (ii) lack of human and financial resources and equipment, (iii) insufficiencies or inadequacies of funding and equipment. As an illustration, India devote fourfold funding to research in comparison to West Africa; South Africa, fourfold, Brazil and Russia fivefold and China sevenfold. ‘‘This high international collaboration rate might indicate a structural dependence of African science, owing to the resources offered by advanced countries to help alleviate infrastructural and financial constraints are hampering many African science system’’ (Toivanen & Ponomariov, 2011). Furthermore, Sub-Saharan Africa’s countries are far from the target of allotting 1% of their GDP to research funding as they committed to (Boshoff, 2009; UNESCO, 2015), e.g. in the Lagos plan of action (Organization of African Unity, 1980). In these conditions, science, technology and innovation could not get priorities and could not really contribute to wealth creation and hence the improvement of population life conditions.

4. Collaboration between countries and continents in the West African scientific publishing

This chapter explores the number of papers with multi-co-authorship, collaboration with other African countries and regions, collaboration with other continents and intraregional collaboration. It is based on Mêgnigbêto (2013a) and Mêgnigbêto (2013b).

4.1. Introduction

Research is a costly and time consuming activity. Researchers often cooperate in order to achieve publications. Through cooperation, they reduce time, costs, personal investment and increase their productivity; they share skills, knowledge, data, ideas, equipment and research results; they benefit from advice or help from each other, gain experience or train apprentices, obtain cross-fertilization across disciplines, etc. (Bordons & Gomez, 2000; Katz & Martin, 1997; Toivanen & Ponomariov, 2011; Wagner, 2006). A collaboration process may imply two or more scientists from the same laboratory, from different laboratories within the same institution, from different institutions within the same country or from different institutions from different countries.

It is well known that Africa's share to the World scientific output is negligible. Adams et al. (2010) found that from 1999 to 2008, the volume of the whole of Africa’s output per year is the same as that of the Netherlands. Pouris and Pouris (2009) attributed less than 2% to Africa's share to the global science output over the period 2000-2004, UNESCO Institute of Statistics (2005) 1.4% in 1990 and the same in 2002. (Toivanen & Ponomariov, 2011) stated that Africa has the weakest research infrastructure and capacity among continents. Tijssen (2007) indicated that Africa’s share in the global research decreased dramatically from 1% in 1987 to 0.7% in 1996 and that the continent has lost 11% of its share in global science since its peak in 1987. He added that Sub-Saharan science has lost almost a third. But these decreases don’t mean an absolute diminishing of the volume of publications, but rather an increase less than the worldwide rate, the same study warned. It is also well known that African research is dominated by non-African researchers (Bierschenk & Mongbo, 1995; Boshoff, 2010; Dahoun, 1997; Gaillard, 2010; Tijssen, 2007; Toivanen & Ponomariov, 2011). This situation is due to i) how lowly equipped the Continent was; indeed, some research areas require heavy equipment (Toivanen & Ponomariov, 2011); ii) the weak investment African countries and supra national institutions dedicate to the science, technology and innovation sector (Adams et al., 2010; Pouris & Pouris, 2009; Tijssen, 2007; Toivanen & Ponomariov, 2011; UNESCO Institute of Statistics, 2005); iii) developed countries that often allot for funding of research activities within their cooperation programmes only; in this case, African researchers contributed to collect data developed countries researchers analysed and used for publications; in this line, Bierschenk and Mongbo (1995) noticed that

Beninese research is done in the shade or the wake of development projects and programmes financed by donors and Toivanen and Ponomariov (2011) stressed that the strategic partnership between Africa and the European Commission signed in 2007 put a particular emphasis on building collaborative links between African regions, sub-regions, and European partners;

The African Union divided the Africa continent into five regions based on cultural, historical, geographical and economic criteria.[39] They are the Northern (6 countries),[40] the Western (15 countries), the Central (9 countries), the Eastern (13 countries) and the Southern (10 countries) (cf.Table 2-1). Eight of the West African Member States are former French colonies namely Benin, Burkina Faso, Cote d'Ivoire, Guinea, Mali, Niger, Senegal and Togo; Guinea-Bissau and Cap Verde are former Portuguese colonies; Nigeria, Ghana, Sierra Leone, and Gambia are former British colonies; and, Liberia, a country created in earlier 19th century by the former enslaved blacks returned back from the United States of America. Hence, three international language communities are distinguished in the region that are respectively French speaking, Portuguese speaking and English speaking. The region has also two economic communities: i) the West African Economic and Monetary Union (WAEMU) that groups together the French speaking countries, minus Guinea to which is added Guinea-Bissau, and ii) the Economic Community of West Africa States (ECOWAS) that groups together all the 15 countries.

The African Union, African regional economic communities and individual countries have recognized the role of science and technology for poverty alleviation and development (Toivanen & Ponomariov, 2011). Besides, such regional integration institutions, financial institutions and UNESCO as well as other international institutions have encouraged individual countries in formulating and implementing science, technology and innovation policy. Article 27 of the Economic Community of West African States (ECOWAS) Revised Treaty (ECOWAS Commission, 1993) clearly spells out that member states shall ensure proper application of science and technology to the development of agriculture, transport and communications, industry, health and hygiene, energy, education and manpower and the conservation of the environment. The ECOWAS' Commission established a *Department in charge of Culture, Education, Science and Technology* in January 2007. The ECOWAS Policy on Science and Technology (ECOPOST) and its action plan were adopted on 24 March 2012. Especially, the ECOPOST should help ECOWAS Member States to master all science fields required for the emergence of a scientific community able to compete and to exchange with the best research teams worldwide. Also at national level, policies have been set up to make research contribute to improve life conditions.

[39] Resolution CM/Res.464 (XXVI) adopted by the African Unity Organization (now African Union) Council of Ministers meeting in its twenty sixth ordinary session in Addis-Ababa (Ethiopia) from 23 February to 1st March 1976. The countries list was updated in 2004.

[40] Even though Morocco is an African country and belongs to the North from a geographical point of view, it is not member of the African Union due to political reasons. Therefore, it is not considered in the African Union's classification. However, in this study, we included it into the Northern region.

ECOWAS and African Union Member States have committed in many occasions to allot 1% of their Gross Domestic Product to fund research activities, in accordance with the Lagos Action Plan (Organization of African Unity, 1980).

4.1.1. Research questions

It is clear from the institutional and legal frameworks set up and from the policy documents referred to above that authorities (at national, regional or continental level) are aware of the importance of science and technology for development. It is too soon to assess the real impact of these measures or policy statements on the scientific output in West Africa or in Africa. However, it is useful to draw the state of scientific publishing that may serve later for comparison purpose. This study will answer the following research questions: i) To which extent do West African countries collaborate with each other? ii) What are the main research partners of West Africa in Africa and worldwide? iii) What is the share of international collaboration in West Africa scientific output both at the level of individual countries and the whole region?

4.1.2. Objectives

The objectives of this chapter are double: to produce basic statistics on intra-regional and international scientific collaboration in West Africa and to identify the main partners of West Africa both in Africa and worldwide.

4.2. Literature review

4.2.1. Scientometric studies in Africa

Scientometric studies on the whole or parts of Africa are very limited, compared to other continents, even though an evident interest has been registered recently (NEPAD Planning and Coordination Agency, 2010; Tijssen, 2007). They may be distinguished in four categories: i) studies related to the whole or almost the whole Africa (e.g. Adams et al., 2010; Confraria & Godinho, 2015; Omwoyo Bosire Onyancha & Maluleka, 2011b; Pouris & Pouris, 2009; Toivanen & Ponomariov, 2011; Urama et al., 2010); ii) studies related to one or more African regions or several countries from different African regions (e.g. Arvantis et al., 2000; Boshoff, 2009, 2010; Dahoun, 1999; NEPAD Planning and Coordination Agency, 2010; Onyancha, 2009; Pouris, 2010; Tijssen, 2007; Waast, 2002);[41] iii) papers that are country specific with one, two or three countries (e.g Dahoun, 1997; Gaillard, 2010; Jeenab & Pouris, 2008; Mêgnigbêto, 2012, 2013c, 2013e, 2014d; Mêgnigbêto & Houzanmè, 2012; Onyancha,

[41] Waast (2002) gave an overview of cases studies on 15 African countries: Egypt, Tunisia. Algeria, Morocco at the Northern Africa, Senegal, Burkina, Cote d'Ivoire, Cameroon, Madagascar, Nigeria, Kenya, Tanzania, Zimbabwe, Mozambique and South Africa. Each country had been the object of a specific report.

2009) and iv) those that are field specific (e.g. Onyancha & Ocholla, 2007; Onyancha & Maluleka, 2011a; Pouris, 1989, 1991). Whereas some regions or countries, like the South African Development Community (SADC) and South Africa, have been steadily explored, others lack examination. Certain papers from those referred to above dealt with collaboration alongside with productivity, fields, co-authorship and citations analyses. Some others dealt only with collaboration.

4.2.2. Research collaboration in Africa

Toivanen and Ponomariov (2011) and Adams et al. (2010) studied the whole of Africa's research collaboration pattern. They distinguished three separate "scientific regions" that neither match each other nor match the African Union categorization; they are the Northern (6 countries), the Western (23 countries) and the Southern-Eastern (25 countries) in the case of the former, the Northern (5) countries, the Central (34 countries) and the Southern (14 countries) in case of the latter. Toivanen and Ponomariov (2011) reported an increasing trend in the number of authors who contributed to an article from 4.1 in 2005 to 4.5 in 2009; they underlined the concentration of the growth in the group of papers with 5 or more authors, illustrating the importance of collaboration in Africa science. The same trend in co-authorship was noticed by Mêgnigbêto (2013e) while studying the scientific output of three West African countries, especially Benin, Ghana and Senegal.

Collaboration between African regions is too low indicating "the absence of regional integration in the African innovation systems" (Toivanen & Ponomariov, 2011) . The "scientific regions" referred to above were weakly connected. Only a few countries served as major research hubs; they are Kenya, Tanzania, Uganda, South Africa, Egypt, Nigeria and Cameroon (Toivanen & Ponomariov, 2011). The Northern region has no direct links neither with the Western nor with the Southern-Eastern ones (Adams et al., 2010; Toivanen & Ponomariov, 2011). Collaboration between African countries is weak too (Adams et al., 2010; Onyancha & Maluleka, 2011b; Toivanen & Ponomariov, 2011). Adams et al. (2010) identified a French speaking group formed around Cameroun and an English speaking one including Nigeria, Ghana, Gambia, and Kenya with its geographical neighbours. Nigeria acts as a bridge between the two languages areas; it also connects strongly to South Africa. Conversely, the international collaboration rate is higher. It has risen very significantly from 30% in the early 1990's up to 50% starting from 2000 (Tijssen, 2007). While studying the 11 central African countries output, Boshoff (2009) found 80% of the region's papers have a foreign address; Onyancha and Maluleka (2011b) reported the same finding Africa as a whole. Tijssen (2007) reported that the profiles of African countries regarding international cooperation showed significant differences, ranging from 29% to 87%. The main partners of both African regions and countries are European and North American countries, especially, the United Stated of America, the United Kingdom, France and Germany.

African countries have strong ties with their former European colonizers like France and the United Kingdom (Boshoff, 2009, 2010; Dahoun, 1999; Mêgnigbêto, 2012, 2013e; NEPAD Planning and Coordination Agency, 2010; Pouris, 2010) illustrating the continuing legacy of the colonisation. The presence of the USA among the main African partner countries is the effect of African researchers who have studied in the USA and have maintained links with their research groups after they returned back home (Adams et al., 2010). As far as intra African collaboration is concerned, language, culture and geographical close-up were identified as drivers (Adams et al., 2010; Boshoff, 2009; Onyancha & Maluleka, 2011b). South Africa is the main African partner country for many Africa Member States. It dominates the SADC regional output and acts as the "political North" (Boshoff, 2010).

The main factors explaining the current African science situation are the weak research infrastructure the continent has and the weak investment in science and technology. Boshoff (2009) underlined that Sub-Saharan Africa's countries "are struggling to reach the target of allocating at least 1% of GDP to R & D" as they committed to.

4.2.3. Main findings of previous research

The most important conclusions from the papers reviewed above are: i) Africa's share to the World output is very negligible, ii) the big science producers in Africa are Egypt in the North, South Africa in the South, Kenya in the East and Nigeria in the West; Cameroon in the Central region and Tanzania in the East are among middle producers; iii) these countries also drive collaboration links; therefore, they are the backbone of the scientific collaboration network in Africa and connect African regions and Africa to the World; iv) language, culture, colonial ties and geographical close-up are criteria for collaboration; v) hence, the main African countries' common partners are former colonizers, namely France and United Kingdom; however, USA follows as the third common partner country even though it has no former colony on the Continent; vi) cooperation between developing countries is weak; so is cooperation between African countries; vii) and, viii) developed countries are the major non-African partners of African countries; iv) countries with the same region collaborate more than they do with countries from another region.

Western Africa as defined by the African Union lacks these kinds of studies both regarding the scientific output measuring, country profiles comparing, intra-regional or international collaboration indicators computing.

4.3. Methods and data

4.3.1. Defining research collaboration

Research collaboration is not easy to define or measure. It is often used as synonymous of multiple authorships or multiple addresses; that is, research collaboration occurs if two or more scientists cooperate and publish (Bordons &

Gomez, 2000, p. 198; Katz & Martin, 1997). Research collaboration is a social process and the idea of collaboration is far from simple, it can take many forms (Bordons & Gomez, 2000, p. 198; Katz & Martin, 1997). Therefore, a central question arises: how to measure research collaboration? Katz and Martin underlined that only some more tangible aspects of collaboration work could be quantified because the phenomenon may be governed by complexity of human interaction. They also gave the advantages of using co-authorship as a measure in research collaboration evaluating (See also Bordons & Gomez, 2000, p. 199): i) it is invariant and verifiable, ii) it is relatively inexpensive and practical, iii) the sample one may analyse using the indicator can be very large, iv) the results it yields is statistically more significant. The measure presents however some limitations (Bordons & Gomez, 2000, pp. 199–200; Katz & Martin, 1997, p. 2; cf. Subramanyam, 1983, p. 35) : i) the precise nature and magnitude of collaboration cannot be easily determined; ii) both the nature and magnitude of contribution of each collaborator are likely to change during the course of a research project; iii) only some of the more tangible aspects of a collaborative piece of work can be quantified while others most certainly cannot ; iv) even a qualitative assessment of collaboration is extremely difficult because of the indeterminate relationship between quantifiable activities and intangible contributions; iv) not all collaboration results in publication, v) the method of attributing co-authorship (full or fractional count), etc. Despite these limitations, in this study, we used multiple occurrences to assess collaboration, indeed, in Academia, co-authorship is the most visible indicator of scientific collaboration and has thus been frequently used to measure collaborative activity (Abbassi et al., 2012; Bordons & Gomez, 2000; Katz & Martin, 1997).

In practice, only individuals collaborate; by doing so, they engender collaboration ties between institutions they are working in. Co-authorship analysis has been extended to the organizational and institutional aspect of collaboration. Therefore, the principle of collaboration apply also to research groups within a department, departments within the same institution, institutions, sectors, and geographical regions (Abbassi et al., 2012; Katz & Martin, 1997, p. 9). Hou et al. (2008) spoke of level of collaboration and distinguished i) micro level that involves individuals, ii) meso level with institutions and iii) macro level with countries. Information about authors to assess collaboration is found in affiliation information (or addresses).

Research collaboration at a level occurs if at least two scientists cooperated and involved two different actors from the considered level. Bordons and Gomez (2000) defined the two main research collaboration indicators : i) the co-authorship index, that is the average number of authors per document, ii) the collaboration rate which is the percentage of papers resulting from collaboration between at least two actors.

4.3.2. Data source

A search was performed on Web of Science in April 2012 to retrieve all the publications co-authored by at least one scientist from any West African country. The databases searched were Science Citation Index Expanded (SCI-EXPANDED), Conference Proceedings Citation Index- Science (CPCI-S), Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH) and Index Chemicus (IC). All languages and all types of document were selected. The exact search expression entered into the advanced search form was (cu=dahomey or cu=benin) or (cu=ivory coast or cu=cote ivoire) or cu=niger or cu=senegal or (cu=cabo verde or cu=cape verde) or cu=senegambia or cu=gambia or cu=ghana or cu=nigeria or cu=togo or cu=mali or cu=liberia or cu=sierra leone or cu=guinea or (cu=burkina faso or cu=upper volta) or cu=guinea-bissau. The search returned 75,176 records.

4.3.3. Data treatment

4.3.3.1. Regional data

From the results, records related to the period 2001-2010 (a 10-years period) were extracted because this period represents the last complete decade and accounts for approximately 40% of the region's total production. The results (29,323 records) were downloaded and merged into a unique file. A bibliographic database was created with CDS/ISIS.[42] The database counts several fields, but those we are interested in are *Affiliations* and *Corresponding authors*; indeed, only these two contain authors or co-authors addresses. The content of the file was imported into the database thanks to a program coded in CDS/ISIS Pascal [43] (See Appendix 1 for an example of a CDS/ISIS Pascal programme). Another CDS/ISIS Pascal program was used to extract country names from affiliations data and add them into the inverted file for retrieval purposes.

While checking for the consistency of the data, it appeared that the part of the Web of Science search expression (cu=guinea) had selected not only records of authors affiliated to Guinea but also those related to authors affiliated to Guinea Bissau, Papua New Guinea and Equatorial Guinea (these three country names all contain the word *guinea*, indeed). The last two countries don't belong to the West African region; therefore, associated records should be removed from the database. Thus, we run three searches on the CDS/ISIS database: i) the first selected records related to the 15 West African countries; ii) the second selected records related to Equatorial Guinea and Papua New Guinea (955); iii) the third selected the records these two countries shared with any West African country (12); iv) the fourth stage consisted in removing the results of the latter search from the set selected by the former. The remaining records (955 − 12 = 943) represent the irrelevant ones and were deleted

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[42] CDS-ISIS is text database management software developed and distributed by UNESCO. (http://www.unesco.org/isis).

[43] CDS/ISIS provides a programming language "designed to develop CDS/ISIS applications requiring functions which are not readily available in the standard package" (UNESCO, 1989b). This programming language enables users to extend functions of the standard package, to make it more robust and in order to meet users' specific needs (Mêgnigbêto, 1998).

from the CDS/ISIS database. Therefore, the total number of records analysed in this chapter is 29,323 - 943 = 28,380.

Web of Science uses countries and territories names in affiliations data. Some territories are not independent or not recognized by the international community (e.g. Taiwan). But, we need countries to compute reliable statistics on collaboration; therefore, in the fields *Affiliations* and *Corresponding authors* of the CDS/ISIS database, we replaced territories names by the name of the countries they depend on. Hence, Martinique, Reunion, Guadeloupe, Guyana, etc. were replaced by France; England, Wales, Scotland and North Ireland were replaced by United Kingdom, Taiwan by China, etc. The records edition function of CDS/ISIS was used for this purpose. Thanks to the CDS/ISIS formatting language[44] and search function, some data were printed into a file and analysed with statistical software or computed directly. Finally, another CDS/ISIS Pascal program was used to generate the countries collaboration network file for analyses with Pajek, a software application for large networks analysis and visualization (de Nooy et al., 2005).

The indicators we computed in this chapter have values ranging from 0 to 1 (or 0% to 100% if expressed as percentage). As a rule of thumb inspired by practices in interpreting association coefficients, we considered an indicator as null or negligible if its value is less than 0.05 (or 5%); if the value is over 0.05 and less than 0.30 (30%) the indicator is weak; it is moderate if the value is between 0.30 and 0.70 (30% and 70%); over 0.7 (e. g 70%), the indicator is strong.

4.3.3.2. Intraregional data

We extracted from this database records related to intra collaboration within the West African region. A paper results from intra collaboration if the affiliations data bear at least two addresses based in at least two different West African countries. For this purpose, we used the CDS/ISIS search function.

The CDS/ISIS search function operates mainly over the inverted file that contains "searchable terms" as initially defined by the database administrator into a file called Field Selection Table (UNESCO, 1989a, pp. 75–86). It admits the Boolean operators OR symbolized by the sign + (plus), AND symbolized by the character * (star) and NOT symbolized by the character ^ (circumflex). It also admits parentheses to prioritize part of a search expression (UNESCO, 1989a, pp. 95–105). Let us assume that A, B, C and D are the names of four countries. The papers country A shared with country B are papers in which both A and B appear in the address field. The corresponding

[44] «The formatting language allows you to define precise formatting requirement for data base records. Through this language, you may select one or more specific data elements in the order you want and optionally insert constant text of your choice, e. g. to label some or all the fields, as well as specify vertical or horizontal spacing requirements (…). The formatting language is therefore the core of many operations and an efficient use of CDS/ISIS requires a thorough knowledge of this techniques» (UNESCO, 1989a).

Boolean expression that permits selecting the set of such papers is *A AND B*. In the CDS/ISIS search language, the search equation becomes *A * B*. Therefore, *A * C* on the one hand and *A * D* on the other hand select the papers A shares with C and those A shares with D respectively. These three search equations could be combined and run at once like the following:

(A* B) + (A* C) + (A * D) (4-1)

.which is also equivalent to

A * (B + C + D) (4-2)

that selects papers A shares either with B, C or D. In the same manner, the three search equations

B * (A + C + D) (4-3)

C * (A + B + D) (4-4)

D * (A + B + C) (4-5)

select papers each country, B, C and D respectively, shared with the remaining three countries. Let us suppose Equation (4-2) be the first search expression run since the CDS/ISIS session has started, Equation (4-3) the second, Equation (4-4) the third and Equation (4-5) the fourth. CDS/ISIS automatically assigns each search expression an identifier which is anything than a number represent the order. CDS/ISIS allows for previous search recalling by entering its number prefixed with the sign (#). Previous search expression may also be part of a new search expression. Therefore, one could combine or prefix with the hash sign (#) the order in the searches history. Thus, the search expression

#1 + #2 + #3 + #4 (4-6)

combines searches 1 through 4 with the Boolean OR (sign +); therefore, it retrieves all the papers countries A, B, C, and D shares with each another, e. g. all the intra A, B, C and D papers.

We wrote search expressions like that in Equation (4-2), considering each of the 15 ECOWAS Member States. For example, the papers Benin shared with any other West African country were selected with the search expression:

benin * (Burkina faso + cape verde + cote ivoire + gambia + ghana + guinea + guinea bissau + liberia + mali + niger + nigeria + senegal + sierra leone + togo) (4-7)

.Such a search expression was built and executed over the database for each of the 15 West African Member States. The fifteen search expressions were then combined into only one search expression (like in Equation (4-6)) of which execution returned

1,302 bibliographic records accounting for 4.59% of the region's total output over the period.

4.4. Results

4.4.1. The extent of the collaboration

Collaboration is often measured by multiple authorships. Therefore, we computed the number of papers in West African scientific output according to the number of authors they have. We distinguished from 1 to 5 authors and 6 and more authors. The curves are shown in Figure 4-1. For the clearness of the figure, trends were not plotted. The percentage of papers with only one author decreased from 10.5 in 2001 to 9.5 in 2010; the percentage of papers with 4 or 5 authors shows the same trend. In opposition, the percentage of papers with 6 and more authors has increased. Besides, Table 4-1 shows that the total number of co-authors per year rose from 6,759 in 2001 to 23,608 in 2010. Conversely, the number of papers per co-author trended downward, from 0.23 at the beginning of the period to 0.19 at the end. These data show the importance the phenomenon of multi authorship, and hence, collaboration in research, is gaining in the West African region; it may also mean that West Africa is following the global trend in science publishing

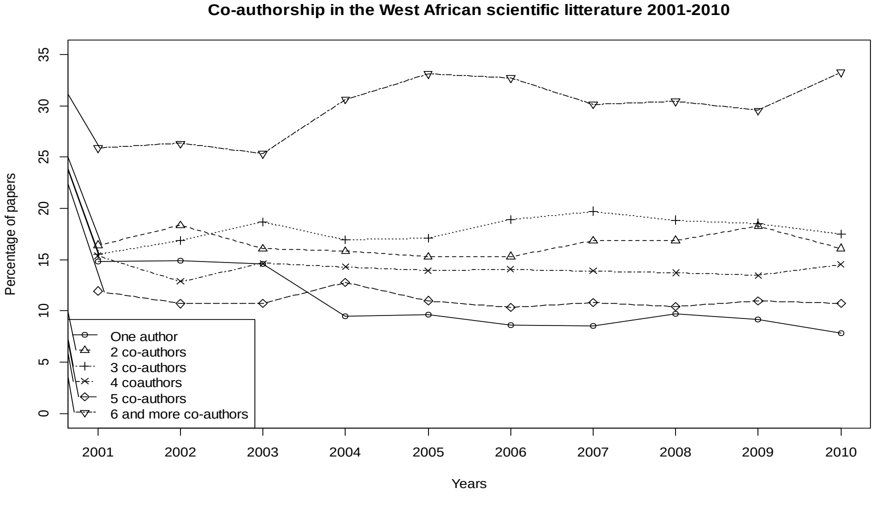

Figure 4-1 Co-authorship in the West African scientific literature

Table 4-1 Co-authorship, number of papers per co-author and number of authors per paper and their cumulative values

Indicator		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Number of co-authors	Number	6,759	7,378	7,858	8,963	12,758	13,437	16,525	18,647	20,758	23,608	136,691
Papers	Number	1,553	1,701	1,826	1,901	2,607	2,693	3,464	3,834	4,291	4,510	28,380
Authors per paper	Number	4.35	4.34	4.30	4.71	4.89	4.99	4.77	4.86	4.84	5.23	4.82 (Average)
Papers per author		0.23	0.23	0.23	0.21	0.20	0.20	0.21	0.21	0.21	0.19	0.21 (Average)

4.4.2. Annual production

The total number of bibliographic references considered in this chapter is 28,280. The repartition per country is presented in Table 4-2. It reveals that, on its own, Nigeria produced more than half the total output of the region, far followed by Ghana (11.29%), Senegal (8.96%), Burkina Faso (6.29%) and Cote d'Ivoire (5.88%). The remaining 10 countries each output less than 5% of the region's total scientific papers. The region's annual production presents an increasing trend and goes from 1,641 in 2001 to 4,617 in 2010 (Figure 4-2). The curve can be best fitted by a linear trend of which equation is $y = 361.45t + 850$ where y is the number of papers and t the period of time (t = 1 in 2001 and $r^2 = 0.96$). Figure 4-2 exhibits i) West Africa's output curve and its linear and fit, ii) West Africa's half output curve, and iii) the Nigerian production curve.

Nigeria is the biggest science producer in West Africa. From 2001 to 2005, it produced about the half the region's total production; however, starting from 2005, its production rose slowly and separated from the curve of half the region's production; the demarcation between the two curves became more pronounced in 2006. From then on, Nigeria scientific output became higher; that is, since 2006, Nigeria has annually being produced more than all the remaining 14 countries grouped together.

Table 4-2 Scientific output of West African countries

Rank	Country	# publications	% West Africa output
1	Nigeria	15,569	54.86
2	Ghana	3,203	11.29
3	Senegal	2,544	8.96
4	Burkina Faso	1,785	6.29
5	Cote d'Ivoire	1,669	5.88
6	Benin	1,335	4.70
7	Mali	1,204	4.24
8	Gambia	986	3.47
9	Niger	586	2.06
10	Togo	433	1.53
11	Guinea	241	0.85
12	Guinea Bissau	225	0.79
13	Sierra Leone	117	0.41
14	Cape Verde	52	0.18
15	Liberia	49	0.17

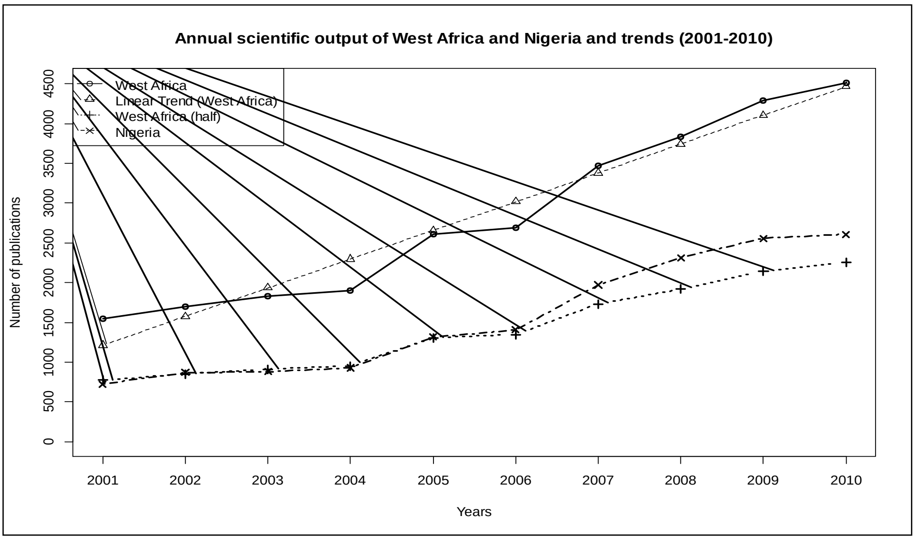

Figure 4-2 Annual scientific production in West Africa and Nigeria

4.4.3. International collaboration at the region level

International collaboration in the context of this section stands for the collaboration of West African countries in publishing with non-West African ones as if West Africa constituted only one country.

4.4.3.1. Trend and main partner countries

Data showed that 151 non-West African countries contributed to the scientific output of West Africa, among them 38 African, 27 American, 40 Asian, 41 European and 5 Oceanian. They shared 14,094 papers accounting for 49.66% of the total output of the region. The lowest international collaboration rate (45.26%) was registered in 2008 and the highest (56.44%) in 2004. Both Figure 4-3 and Figure 4-4 are related to international collaboration in the West African scientific output. The former represents the absolute number of papers; the curve can be best fitted by a linear trend of which equation is $y = 168.95t + 552.2$ where y is the number of papers and t the period of time (t = 1 in 2001 and $r^2 = 0.97$); the latter representing the rate shows a decrease meaning that whereas the number of publications with a non-West African address is trending upward, its rate in less than that of the annual output. This trend may have resulted from the starting of the enrolment of doctoral students by most West African – mainly French speaking – countries at the beginning of the 2000s and the opportunities then created for scientific collaboration at the national level. For comparison purposes, we plotted data related to Nigeria along with those of the entire region. Over the period 2001-2010, the Nigerian average international collaboration rate is lower than that of the region, but higher than half the total of the region.

The top 20 partner countries' shares are computed in Table 4-3. France is ranked first; it contributed to the West African scientific literature with 3,572 papers accounting for 12.59% of the region's output; this number also represents about one quarter of the total papers West Africa shared. Just behind, the USA comes as second partner, with 12.54%, followed by the United Kingdom (10.09%). The fourth partner is Germany, far behind with 4.39%. South Africa is ranked fifth and the first African country with 3%. Out of the top 20 partner countries, 9 are European (France, the United Kingdom, Germany, Belgium, Switzerland, the Netherlands, Italy, Denmark and Sweden), 4 African (South Africa, Cameroon, Kenya and Tanzania), 3 American (the USA, Canada and Brazil), 3 Asian (Japan, India and China) and one is Oceanian (Australia). The top 20 countries shared with West Africa 13,399 papers accounting for 47.21% of the total output and 88.61% of the papers West Africa shared with the rest of the world. Therefore, the region collaborated with a large number of countries, but only a few partner countries concentrated the shared papers.

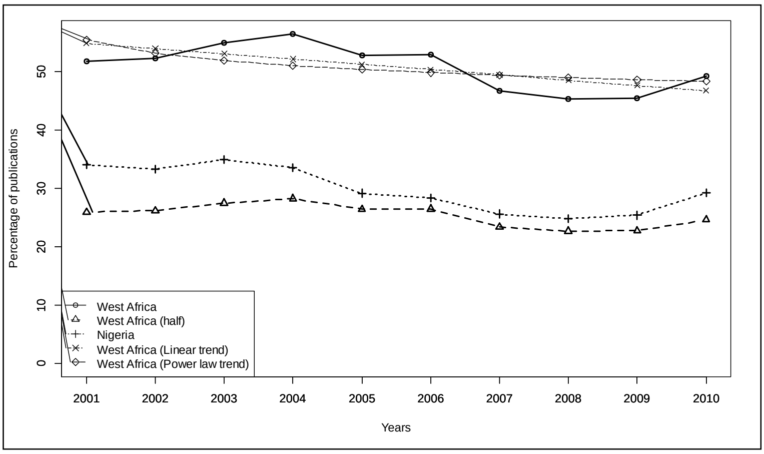

Figure 4-3 International collaboration in West African scientific output

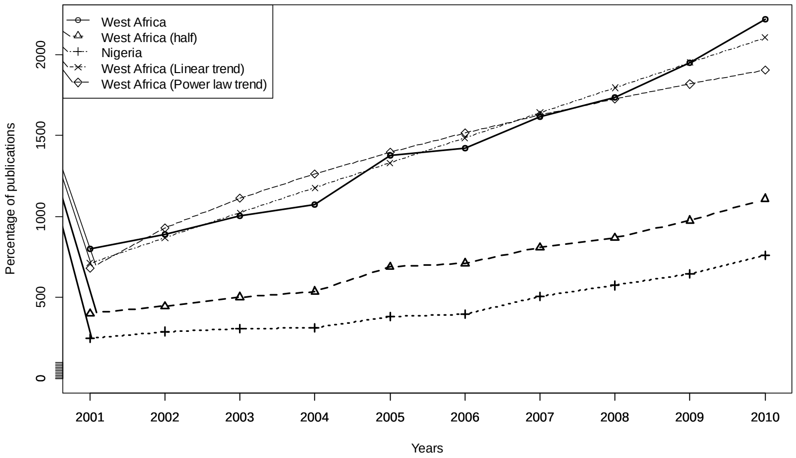

Figure 4-4 Percentage of international collaboration in West African scientific output

Table 4-3 Top 20 partner countries of West Africa and their shares

Rank	Countries	# papers	% West Africa output	% World share
1	France	3,572	12.59	25.35
2	USA	3,560	12.54	25.26
3	United Kingdom	2,863	10.09	20.32
4	Germany	1,245	4.39	8.83
5	South Africa	848	2.99	6.02
6	Belgium	830	2.92	5.89
7	Switzerland	750	2.64	5.32
8	Netherlands	703	2.48	4.99
9	Italy	694	2.45	4.92
10	Canada	474	1.67	3.36
11	Cameroon	457	1.61	3.24
12	Denmark	437	1.54	3.10
13	Kenya	416	1.47	2.95
14	Japan	391	1.38	2.77
15	Sweden	355	1.25	2.52
16	China	344	1.21	2.44
17	India	308	1.09	2.19
18	Australia	307	1.08	2.18
19	Brazil	234	0.82	1.66
20	Tanzania	227	0.80	1.61
	Total	13,399	44.21	88.61

4.4.3.2. Collaboration with continents

Europe is by far the first partner of West Africa with 27.12% (9,655 papers) of contributions followed by America 14.55% (4,240 papers, North and Latin America combined), Africa 8.79% (2,530 papers), Asia 5.29% (1,540 papers) and Oceania 1.29% (367 papers). These shares double if reported to the number of papers with foreign addresses, because the latter accounts approximately for the half the total production. The top 5 partner countries per continent are given in Table 4-4. Column 1 gives the rank, Column 2 the country name, Column 3 the number of papers the country shared with West Africa, Column 4 the country percentage share to the share of the Content it belongs to West Africa's scientific output, that is the number in Column 3 divided by the Continent share to the West Africa scientific output, Column 5 the country's share to the World share to West African output, that is Column 3 divided by the number of West Africa shared with the Rest of the world (i.e. 14,094), and Column 6 the country's share to West African output, that is Column 3 divided by the total output of West Africa (i.e. 28,380).

At the European Continent level, France and the United Kingdom are respectively first and second partner countries with 37% and 29.65% of papers with at least one European address. In America, the USA on its own contributed to more than 4 papers out of 5 the continent shares with West Africa. Globally, these 3 countries, with 8,920 papers accounting for 31.43% of the West African total output and 63.28 % of the papers with non-West African address, are the main partners of West Africa.

4.4.3.3. Collaboration with African regions

Africa counts 53[45] nations categorized into 5 regions: the Northern, the Western, the Central, the Eastern and the Southern (cf.Table 2-1). The Southern region is the first partner of West Africa with 1,092 papers (43.16%), followed by Eastern Africa with 890 papers (35.18%), Central Africa with 666 papers (26.32%) and North Africa with (304 papers (12.02%). These percentage shares are reported to the total Africa's share to the West African region.

The main partners on the Africa continent are South Africa, Cameroon, Kenya, Tanzania, Uganda and Gabon. We were interested in knowing whether at this region level, these countries only drove collaboration links or they shared with other neighbours. Hence, we extracted from the global collaboration network the sub-network containing only the African countries. We considered not West Africa as only one area, but its 15 Member States; therefore, the sub-network counts 53 countries. We then visualized the collaboration network of African countries. Figure 4-5 exhibits the collaboration links between the main countries involved. The threshold was set to 20; it means that only countries and relations with at least 20 papers are shown. Countries were arranged taking into account the African regions: the Western Africa in centre, the Central African on the left, the Northern on the top, the Eastern on the right and the Southern at the bottom. The biggest partner country is South Africa, in the Southern region; on its own, it co-authored 848 papers which represent 77.66% of the Southern Africa region's share to West Africa scientific output. The second important African partner country, Cameroun, shared 547 papers accounting for 82.13% of papers the Central African region contributed to. Kenya and Tanzania, the third and fourth partners belong to the Eastern African region; they shared respectively 416 and 227 papers accounting for 46.74% and 25.50 % of the region. These two countries contributed to 557 papers representing 62.58% of the regions' share to the Western Africa scientific output. The contribution of Uganda (151 papers) and Gabon (103 papers) are moderate in comparison with those of the four former countries. South Africa, Cameroon, Kenya and Tanzania may be qualified as the "main African partners" of the West African region and Uganda and Gabon as "middle partners". Northern Africa has no major relations with West Africa, certainly because, culturally, the former is close-up to the Middle East. The main partners from African regions are the regional biggest information producers.

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[45] The data collected are related to the period 2001-2010. The South Sudan, the 54th African Union was not yet independent at that time

4.4.3.4. Sources countries in West Africa

What is the situation at the local level? In other words, what are the source countries in West Africa that drove links with the four main African partners of the region? Figure 4-6 shows that South Africa's main partner in West Africa is Nigeria (64.62% of the papers South Africa shared); the other West African countries contributions are negligible (the second is Ghana with 13.68%). Nigeria and Senegal shared respectively 31.24% and 24.95% of the Cameroonian contribution to the West Africa scientific production, followed by Burkina Faso (19.04%), Benin (17.29%) and Cote d'Ivoire (12.69%). Figure 4-6 shows the main African partner countries of West African countries and their link. The width of any line that joins any couple of countries also reflects the intensity of the collaboration in terms of number of papers they shared. Statistics related to four main countries' shares to the West African countries are computed in Table 4-5. Each country data were obtained by dividing the number of papers the country at the head of column's shared with a specific West African country by the total number of papers it shared with the whole region.

The collaboration with African countries seems to be language oriented. It points out a number of clusters: i) a French-based cluster grouping together Senegal and Cote d'Ivoire and their collaboration ties with Cameroun; ii) an English-based cluster including Nigeria, Ghana and Gambia with their relationships with Cameroun, South Africa, Kenya and Tanzania, and iii) a balanced cluster with a mixture of French and English Speaking countries: Benin, Mali and Burkina Faso and their ties with Cameroun, South Africa, Kenya and Tanzania. It might be remarked that Nigeria has strong ties with the main countries in each region and West Africa has no major relationships with the Northern Africa. Nigeria therefore, serves as a bridge or hub for West Africa towards the African regions; its high output volume enables it to vary its partners much.

4.4.3.5. International collaboration at West African countries level

The annual international collaboration rate at the regional level ranges from 45.26% to 56.44% with an average of 49.66% over the whole period (2001-2010). What is the situation in each country? What are the countries with the lowest or highest rate? What their main partners are? Table 4-6 computes the annual international collaboration rates of the West African countries from 2001 to 2010. Nigeria has the lowest international rate over the period and, in consequence the lowest average one; 13 countries have a high collaboration rate: Guinea Bissau, Cape Verde, Sierra Leone, Gambia, Mali, Burkina Faso, Liberia, Niger, Benin, Guinea, Senegal, and Côte d'Ivoire) ; one between 60% and 70% (Togo) and only one around 30% (Nigeria). France is ranked first partner of 7 out of 8 of its former colonies and second for the 8^{th}. Portugal is ranked first partner of one of its former colonies (Cape Verde) but 13^{th} for the second (Guinea Bissau). The USA is ranked first partner in case of Ghana, Liberia, Mali, Nigeria, and Sierra Leone, the United Kingdom in case of Gambia only. We computed statistics on the times a continent (by one of the countries belonging to it) appeared in the top 20 list (Table 4-7). For the 15 × 5 = 75 positions related to top five partner countries, 11 European countries appeared 49 times, one American once, 9 African 11 times and one Asian once. France appeared 9 times, the USA 11 and the United Kingdom 10; other countries occurred twice or once. If the top ten positions are taken into account, the USA occurred 15 times, the United Kingdom also 15 times, France 14 times, Belgium 11 times, Germany and Switzerland 10 times each; others countries appeared 6 times or less; they are African countries mainly.

So, globally, France, the USA and the United Kingdom are the first partner of the West African countries.

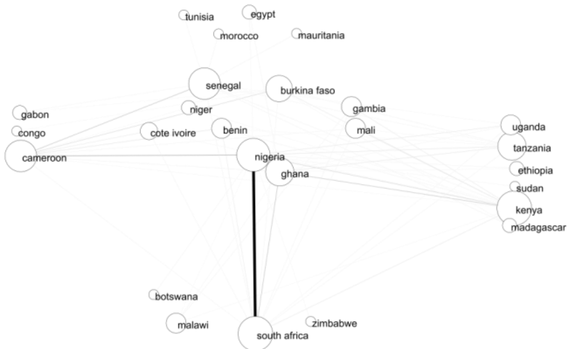

Figure 4-5 West African scientific relations with its African partner countries (number of papers ≥ 20)

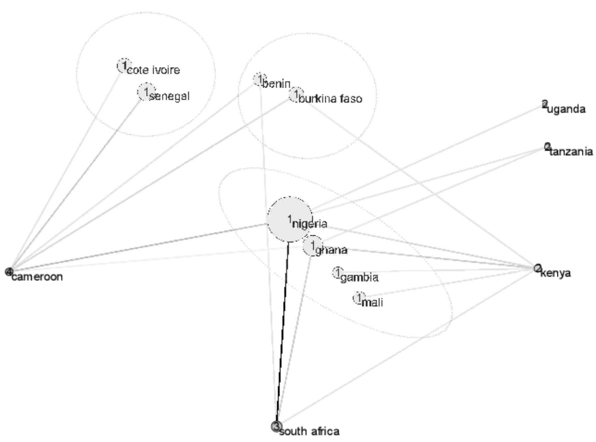

Figure 4-6 West African source countries and their relations with the region's African main partner countries

Table 4-4 West African top 5 partner countries per continent and continents' shares

Rank	Country	# papers	% Continent's share	% World share	% West African
	Africa	**2,530**	**100**	**17.95**	**8.79**
1	South Africa	848	33.52	6.02	2.988
2	Cameroon	457	18.06	3.24	1.610
3	Kenya	416	16.44	2.95	1.466
4	Tanzania	227	8.97	1.61	0.800
5	Uganda	151	5.97	1.07	0.532
	America	**4,240**	**100**	**30.08**	**14.55**
1	USA	3,56	83.96	25.26	12.54
2	Canada	474	11.18	3.36	1.67
3	Brazil	234	5.52	1.66	0.82
4	Mexico	118	2.78	0.84	0.42
5	Colombia	91	2.15	0.65	0.32
	Asia	**1,540**	**100**	**10.92**	**5.29**
1	Japan	391	25.39	2.77	1.38
2	China	344	22.34	2.44	1.21
3	India	308	20.00	2.19	1.08
4	Thailand	114	7.40	0.81	0.40
5	Israel	88	5.71	0.62	0.31
	Europe	**9,655**	**100**	**68.50**	**27.12**
1	France	3,572	37.00	25.35	12.59
2	United Kingdom	2,863	29.65	20.32	10.09
3	Germany	1,245	12.89	8.83	4.39
4	Belgium	830	8.60	5.89	2.92
5	Switzerland	750	7.77	5.32	2.64
	Oceania	**367**	**100**	**2.60**	**1.29**
1	Australia	307.00	81.43	2.18	1.08
2	New Zealand	79.00	20.95	0.56	0.28
3	Papua New Guinea	9.00	2.39	0.06	0.03
4	Fiji	6.00	1.59	0.04	0.02
5	Western Samoa	1.00	0.27	0.01	0.00

Table 4-5 West Africa's top four African partners and their shares to West African countries output

Rank	South Africa		Cameroon		Kenya		Tanzania		All 4 Countries	
1	Nigeria	64.62	Nigeria	31.29	Ghana	76.03	Nigeria	33.04	Nigeria	44.60
2	Ghana	13.68	Senegal	24.95	Nigeria	69.86	Ghana	32.16	Ghana	15.73
3	Benin	6.49	Burkina Faso	19.04	Mali	47.26	Gambia	15.42	Senegal	11.94
4	Senegal	5.78	Benin	17.29	Burkina Faso	41.10	Senegal	15.42	Burkina Faso	10.85
5	Cote d'Ivoire	5.19	Cote d'Ivoire	12.69	Gambia	37.67	Burkina Faso	14.98	Benin	10.51
6	Gambia	4.83	Ghana	10.94	Benin	32.88	Mali	11.89	Mali	7.52
7	Burkina Faso	4.36	Mali	8.75	Senegal	32.88	Benin	10.13	Cote d'Ivoire	6.89
8	Mali	4.25	Niger	4.60	Cote d'Ivoire	18.49	Cote d'Ivoire	5.29	Gambia	6.77
9	Niger	1.18	Togo	2.19	Niger	15.07	Niger	2.20	Niger	3.10
10	Guinea	1.06	Guinea	1.53	Togo	9.59	Togo	2.20	Togo	1.38
11	Togo	0.71	Gambia	1.31	Guinea	4.11	Guinea Bissau	0.88	Guinea	1.21
12	Guinea Bissau	0.35	Eq. Guinea	0.22	Sierra Leone	3.42	Liberia	0.88	Sierra Leone	0.46
13	Sierra Leone	0.35	Cape Verde	0.00	Liberia	2.05	Guinea	0.44	Guinea Bissau	0.40
14	Cape Verde	0.12	Guinea Bissau	0.00	Guinea Bissau	1.37	Sierra Leone	0.44	Liberia	0.23
15	Liberia	0.00	Liberia	0.00	Cape Verde	0.00	Cape Verde	0.00	Cape Verde	0.06

Note: Each country data were obtained by dividing the number of papers the country in head of column's share with a specific West African country by the total number of papers it shared with the whole region.

Table 4-6. West African countries' international collaboration rates

Country	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Over 2001-2010	
											Shared papers	Percentage
Benin	76.19	80.25	83.56	81.31	85.71	84.25	87.16	87.10	83.96	88.94	1,134	84.94
Burkina Faso	67.35	75.00	88.72	92.65	86.52	91.48	90.16	88.79	85.61	87.88	1,547	86.67
Cape Verde	100	n/a	100	100	100	85.71	50.00	100	86.67	100	48	92.31
Cote d'Ivoire	63.20	77.42	82.17	75.34	78.29	84.18	72.88	66.34	71.04	67.83	1,224	73.34
Gambia	83.75	89.04	92.68	90.48	88.12	89.83	83.51	89.76	91.92	90.40	878	89.05
Ghana	71.98	65.82	65.02	73.02	76.03	76.57	71.36	72.75	67.43	70.13	2,277	71.09
Guinea	70.00	72.22	71.43	85.71	85.71	86.84	84.38	95.00	93.10	88.10	204	84.65
Guinea Bissau	100	100	100	90.00	88.00	100	90.00	95.45	100	100	216	96.00
Liberia	100	100	100	80.00	57.14	100	n/a	100	50.00	92.31	42	85.71
Mali	78.43	79.37	89.06	93.67	86.18	88.03	88.36	93.10	91.95	89.89	1,070	88.87
Niger	76.92	78.95	79.07	85.71	82.69	83.02	79.45	91.57	89.29	94.19	501	85.49
Nigeria	34.02	33.30	34.96	33.48	29.16	28.31	25.61	24.84	25.36	29.22	4,425	28.42
Senegal	71.12	81.61	70.69	83.17	76.61	82.46	76.32	78.57	85.05	83.58	2,014	79.17
Sierra Leone	100	83.33	75.00	80.00	100	100	62.50	80.00	96.15	96.55	106	90.60
Togo	46.67	57.14	75.61	84.62	67.44	62.00	68.09	65.96	81.25	73.33	300	69.28
West Africa	51.81	52.32	54.96	56.44	52.80	52.88	46.74	45.26	45.45	49.19	14,094	49.66

Table 4-7. Cumulative number of partner countries per continent and per partner rank level

Partner's rank level	Total positions	Africa		America		Asia		Europe		Oceania	
		Times	# countries	Times	# countries	Times	# countries	Times	# countries	Times	# countries
1	15	0	0	5	1	0	0	10	4	0	0
2	30	1	1	10	1	0	0	19	6	0	0
3	45	5	5	11	1	1	1	28	10	0	0
4	60	7	7	13	1	1	1	39	10	0	0
5	75	11	9	14	1	1	1	49	11	0	0
6	90	20	12	15	2	2	1	53	11	0	0
7	105	25	13	16	2	3	2	61	11	0	0
8	120	31	14	16	2	4	3	69	12	0	0
9	135	41	16	16	2	5	3	73	12	0	0
10	150	49	17	17	2	6	3	78	12	0	0

4.4.4. Intraregional collaboration

4.4.4.1. Annual production

The intraregional production in West Africa slightly rose from 70 papers in 2001 to over threefold (215) in 2010. The associated curve (Figure 4-7) follows an exponential positive trend of which equation is $y = 62.935e^{0.12t}$ where y is the number of papers and t the period of time (t = 1 in 2001 and $R^2 = 0.97$). With this trend, the intra-regional production would double about a period of 5 years 9 months and 9 days. If linear trend is considered, the trend line equation becomes $y = 15{,}69t + 43.86$ with $r^2 = 0.93$. According to this equation, the average annual increase in the intraregional scientific output is about 16 papers. With respect to result of Mêgnigbêto (2013a) that found an annual average of 361 papers,[46] the annual average percentage of the intra-regional collaboration in West African science is 43/361 which leads to 5,18%. This percentage gives the extent to which the intra-regional collaboration in scientific publishing is weak. The real data range from 3.87% to 5.47%. The percentage share of intra-regional collaboration doesn't follow any regular trend. It increases regularly from 4.52% in 2001 and reaches its maximal value 5.45 in 2004 before starting trending downwards; it reaches its lower value in 2007; finally since 2007 it has trended upwards again until 2010.

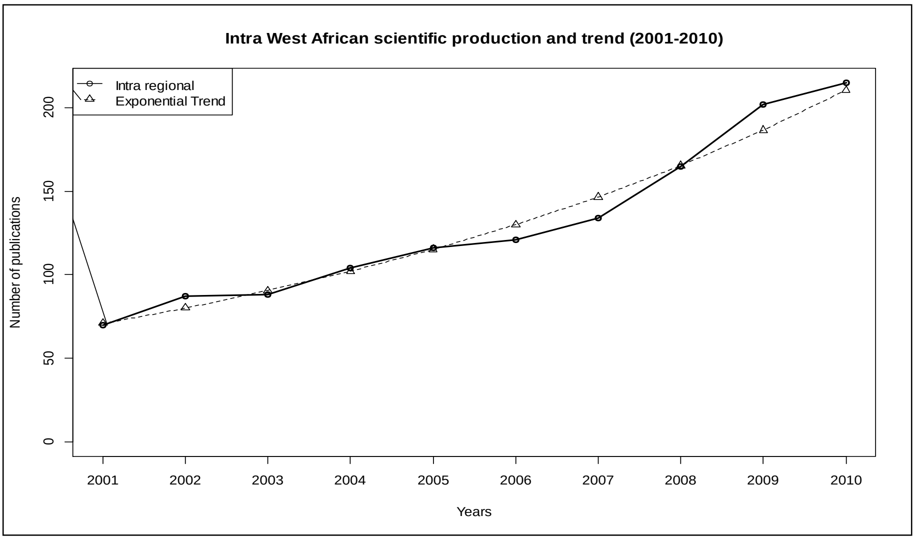

Figure 4-7 Intra West African scientific production and its trend

[46]The annual production curve is best fitted by a linear trend of which equation is $y = 361.45t + 850$ where y is the number of papers and t the period of time (t = 1 in 2001 and $r^2 = 0.96$).

4.4.4.2. Intra-regional collaboration

Section 4.4.3 focused on the cooperation between non West African countries and West African ones. In this section, we focus on the cooperation among West African countries. Statistics on intra-regional collaboration are computed in Table 4-8. The number in a cell indicates either the volume of papers (column #) or the percentage share (column %) the country in the header of row and the country in header of column shared. The diagonal, in bold, contains the total number of papers a country produced over the period or 100%. The percentage shares are obtained by dividing the share to the country in the header of row (Column #) by the total scientific output of the country in the header of column).

Even though in absolute numbers, the contribution of a country to the output of another country is the same as the contribution of the latter country to the scientific output of the former, their percentage shares differ because two different countries have not exactly the same volume of output; for example, Nigeria and Ghana shared 130 papers (Row Nigeria and Column Ghana # or Row Ghana and Column Nigeria #); in percentage however, Nigeria 's share to the Ghanaian production is 4.06 (Row Nigeria, Column Ghana %); the Nigerian volume of papers is 5 times the Ghanaian; therefore, Ghana's share to the Nigerian production in 5 times smaller (0.83%) (Row Ghana, Column Nigeria #). The last line of Table 4-8 aggregates to the region level the contributions of West Africa to each West African country science. Nigeria shared only 2.59% of its production with the other West African countries. Niger depends more on the region than any other country; it shared approximately one third of its production.

The number of papers any couple of West African countries shared ranges from 0 to 130. In percentage of the countries' total output, it varies from 0 to approximately 22. 31 country pairs of countries have no relations, that is, the number of papers they shared is 0. Nigeria and Ghana have the highest absolute share (130 papers). Considering the nature of the relationship and the number of countries, the number of country pairs expected is 15 × 14/2 = 105. 18 missing relations out of the 31 (i.e. (51.61%) are related to the two Portuguese speaking countries; it's a measure of the extent to which they are embedded (or not) in the collaboration network in West Africa.

As far as the shares in percentage are concerned, the number of data doubled because the share of country A to the output of country B is no longer equal to the share of country B to the output of country A. Each of the 15 West African countries, hence, may have relationship with the 14 others; therefore, we expected 15 × 14 = 210 couples of countries' statistics. Bilateral cooperation intensities are below 5% in case of 198 couples of countries (94%); the remaining 12 couples of countries have cooperation intensity lower than 20%. No West African country dominated the intraregional collaboration by having strong links with several countries. Portuguese countries connected to only few countries. Therefore, we can conclude that the intra-regional collaboration is negligible or weak.

Table 4-8. Intra West African collaboration (number of papers and percentage shares).

	Benin		Burkina Faso		Cape Verde		Cote d'Ivoire		Gambia		Ghana		Guinea		Guinea Bissau	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Benin	**1,335**	**100**	62	3.47	0	0.00	59	3.54	5	0.51	50	1.56	12	4.98	0	0.00
Burkina Faso	62	4.64	**1,785**	**100**	0	0.00	91	5.45	13	1.32	63	1.97	19	7.88	0	0.00
Cape Verde	0	0.00	0	0.00	**52**	**100**	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Cote d'Ivoire	59	4.42	91	5.10	0	0.00	**1,669**	**100**	6	0.61	33	1.03	20	8.30	0	0.00
Gambia	5	0.37	13	0.73	0	0.00	6	0.36	**986**	**100**	30	0.94	15	6.22	49	21.78
Ghana	50	3.75	63	3.53	0	0.00	33	1.98	30	3.04	**3,203**	**100**	7	2.91	1	0.44
Guinea	12	0.90	19	1.06	0	0.00	20	1.20	15	1.52	7	0.22	**241**	**100**	11	4.89
Guinea Bissau	0	0.00	0	0.00	0	0.00	0	0.00	49	4.97	1	0.03	11	4.56	**225**	**100**
Liberia	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.03	2	0.83	0	0.00
Mali	38	2.85	85	4.76	1	1.92	30	1.80	16	1.62	38	1.19	13	5.39	0	0.00
Niger	17	1.27	50	2.80	0	0.00	21	1.26	3	0.30	15	0.47	6	2.49	0	0.00
Nigeria	88	6.59	41	2.30	0	0.00	41	2.46	28	2.84	130	4.06	4	1.66	0	0.00
Senegal	56	4.19	118	6.61	1	1.92	69	4.13	54	5.48	39	1.22	28	11.62	16	7.11
Sierra Leone	1	0.07	2	0.11	0	0.00	0	0.00	1	0.10	3	0.09	5	2.08	0	0.00
Togo	50	3.75	49	2.75	0	0.00	20	1.20	2	0.20	19	0.59	6	2.49	0	0.00
West Africa	**307**	**23.00**	**409**	**22.91**	**1**	**1.92**	**248**	**14.86**	**160**	**16.23**	**303**	**9.46**	**74**	**30.71**	**54**	**24.00**

Table 4-8 (continuous). Intra West African collaboration (number of papers and percentage shares).

	Liberia		Mali		Niger		Nigeria		Senegal		Sierra Leone		Togo	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Benin	0	0.00	38	3.16	17	2.90	88	0.57	56	2.20	1	0.86	50	11.55
Burkina Faso	0	0.00	85	7.06	50	8.53	41	0.26	118	4.64	2	1.71	49	11.32
Cape Verde	0	0.00	1	0.08	0	0.00	0	0.00	1	0.04	0	0.00	0	0.00
Cote d'Ivoire	0	0.00	30	2.49	21	3.58	41	0.26	69	2.71	0	0.00	20	4.62
Gambia	0	0.00	16	1.33	3	0.51	28	0.18	54	2.12	1	0.86	2	0.46
Ghana	1	2.04	38	3.16	15	2.56	130	0.84	39	1.53	3	2.56	19	4.39
Guinea	2	4.08	13	1.08	6	1.02	4	0.03	28	1.10	5	4.27	6	1.39
Guinea Bissau	0	0.00	0	0.00	0	0.00	0	0.00	16	0.63	0	0.00	0	0.00
Liberia	**49**	**100**	0	0.00	0	0.00	2	0.01	0	0.00	3	2.56	0	0.00
Mali	0	0.00	**1,204**	**100**	50	8.53	37	0.24	66	2.59	2	1.71	15	3.46
Niger	0	0.00	50	4.15	**586**	**100**	68	0.44	46	1.81	1	0.86	9	2.08
Nigeria	2	4.08	37	3.07	68	11.60	**15,569**	**100**	37	1.45	7	5.98	18	4.16
Senegal	0	0.00	66	5.48	46	7.85	37	0.24	**2,544**	**100**	3	2.56	16	3.70
Sierra Leone	3	6.12	2	0.17	1	0.17	7	0.05	3	0.12	**117**	**100**	0	0.00
Togo	0	0.00	15	1.25	9	1.54	18	0.12	16	0.63	0	0.00	**433**	**100**
West Africa	**6**	**12.24**	**223**	**18.52**	**184**	**31.40**	**403**	**2.59**	**399**	**15.68**	**20**	**17.09**	**129**	**29.79**

4.4.4.3. Sources

Papers resulting from the intra-regional collaboration in West Africa were published in 492 journals searched by their ISSN over the CDS/ISIS database. Each of them occurred 1 to 68 times; 24 published over 10 papers with a total of 474 papers (Table 4-9). Two of them are published in Africa: African Journal of Biotechnology (AJB) – 25 papers - and African Journal of Agricultural Research 10 papers.

Table 4-9. Sources of West African intraregional papers

Rank	Journal title	ISSN	# articles	% articles
1	The American Journal of Tropical Medicine and Hygiene	0002-9637	68	5.22
2	Tropical Medicine and International Health	1360-2276	49	3.76
3	Malaria Journal	1475-2875	28	2.15
4	Acta Tropica	0001-706X	25	1.92
5	African Journal of Biotechnology (AJB)	1684-5315	25	1.92
6	Cahiers d'Études et de Recherches Francophones / Agricultures	1166-7699	20	1.54
7	Annals of Tropical Medicine and Parasitology	0003-4983	17	1.31
8	AIDS	0269-9370	17	1.31
9	The Lancet	0140-6736	15	1.15
10	Vaccine	0264-410X	13	1.00
11	The Journal of Infectious Diseases	0022-1899	12	0.92
12	Nutrient Cycling in Agroecosystems	1385-1314	12	0.92
13	Transactions of the Royal Society of Tropical Medicine & Hygiene	0035-9203	11	0.84
14	Annals of Nutrition and Metabolism	0250-6807	11	0.84
15	PLos One	1932-6203	11	0.84
16	RMV: Revue de Médecine Vétérinaire (Toulouse)	0035-1555	10	0.77
17	Bulletin of the World Health Organization	0042-9686	10	0.77
18	Biology and Fertility of Soils	0178-2762	10	0.77
19	Crop Protection	0261-2194	10	0.77
20	Field Crops Research	0378-4290	10	0.77
21	International Journal of Tuberculosis & Lung Disease	1027-3719	10	0.77
22	Journal of Food Agriculture and Environment	1459-0255	10	0.77
23	Infection, Genetics and Evolution	1567-1348	10	0.77
24	African Journal of Agricultural Research	1991-637X	10	0.77

4.4.4.4. International collaboration within the intra-regional science publishing

1,027 papers out of the 1,302, i.e. 78.88%, are shared with non-West African countries. The annual share of internationally co-authored papers varies less over the period. It ranges from 75 to 81%. It is higher than the total internationally co-authored papers in the region over the same period which is less than 50% (cf. (Mêgnigbêto, 2013a). The top ten partner countries and their shares. The intra-regional collaboration papers are co-authored with researchers from 133 countries; they contributed 1 to 386 papers. The top-10 partner countries are listed in Table 4-10.

Table 4-10. Partner countries of the intra West African scientific output

Rank	Partner	#papers	Percentage share	Share to the internationally co-authored papers
1	France	386	29.65	37.59
2	USA	228	17.51	22.20
3	United Kingdom	215	16.51	20.93
4	Kenya	102	7.83	9.93
5	Switzerland	99	7.60	9.64
6	Cameroon	97	7.45	9.44
7	Belgium	92	7.07	8.96
8	Netherlands	82	6.30	7.98
9	South Africa	78	5.99	7.59
10	Germany	70	5.38	6.82
11	Tanzania	67	5.15	6.52
12	Denmark	58	4.45	5.65
13	Italy	53	4.07	5.16
14	Uganda	46	3.53	4.48
15	Canada	40	3.07	3.89
16	Sweden	39	3.00	3.80
17	Madagascar	28	2.15	2.73
18	Malawi	26	2.00	2.53
19	Spain	22	1.69	2.14
20	India	21	1.61	2.04
21	Morocco	21	1.61	2.04
22	Congo	20	1.54	1.95
23	Gabon	20	1.54	1.95

4.5. Discussion

The main findings of this study are: i) the phenomenon of co-authorship is increasing in West African scientific literature; ii) Nigeria is responsible for more than half the regional scientific output; iii) the region shared with the world almost one half its production; iv) the main partner countries are France, the United Kingdom and the USA both at the regional and individual country levels; hence, Europe and America are the main partner continents; v) intra-regional collaboration is negligible; vi) the collaboration with African regions is also weak and is driven by a few key countries.

4.5.1. Multi authorships is trending upward

The phenomenon of multi authorships in scientific papers is increasing in West Africa science. It has already been noticed by several previous global studies like Adams (2012), Bordons & Gomez (2000;) and Toivanen & Ponomariov (2011). Bordons and Gomez (2000) underlined that in global science, the number of co-authors per paper has been trending upward (Adams, 2012; Mêgnigbêto, 2013e) in recent decades and the number of single-authored papers has been decreasing. West Africa therefore is not at odds with the global trend. Scientists are therefore aware of the benefit of collaboration and are taking advantage of it. Literature also underlined that the phenomenon has different patterns depending on the discipline. For example, single-authored documents are still the norm in the social sciences and humanities while they are the exception in other areas (Bordons & Gomez, 2000, p. 210). Our study is global and didn’t intend to compute this indicator per field.

4.5.2. Nigeria, the local leader

Nigeria is responsible for over one half the region's annual scientific outputs. This result is in accordance with Adams et al.’s (2010) conclusions that listed Nigeria, as the lone West African Member State, among the six nations dominating Africa science; it also confirms Dahoun (1999) qualifying Nigeria as “the leader” in scientific production on the Black continent, and concurs to the findings of Gaillard (2010) and SCimago (2007). Several factors may explain the ranking of Nigeria : i) Nigeria is the largest country of West Africa by its area; ii) Nigeria is also the biggest country regarding the population size; iii) besides, Nigeria is the only West Africa Member State with domestic journals indexed by Web of Science.[47] A search run in the 2011 Journal Citation Report Science Edition (Thomson Reuters, 2011) retrieved 5 Nigeria-based journals; another search in the CDS/ISIS database returned an additional 2

[47] Contrary to the situation in the French African colonies, the Britain African ones had established universities. So, early after their independence, they engaged their universities in respecting the highest European standards. Their ambition to achieve excellence was expressed in the creation of good reputations scientific journals (Eisemon, 1982; Lebeau, 1997). Therefore, the presence of Nigerian journals in the Web of Science is somewhat a result of colonial legacy.

journals.[48] The seven journals published together 1,848 articles. 6 out of the 7 journals are published by the publisher *Academic journals*.

A hypothesis test for the Pearson's correlation coefficient between the volume of output and the size of population revealed a moderate to strong association ($r = 0.62$, $p = 0.013$, $\alpha = 0.05$). Therefore, the size of population may have influenced the volume of output. In order to eliminate this effect, we computed the number of papers per inhabitant in 2010 for all the 15 countries, taking into account the total output over the period 2001-2010 and the population in 2010. Nigeria is ranked 9th instead, behind Gambia (1st), Senegal (2nd), Benin (3rd) (Table 4-12). Dahoun (1999) used the same indicator that ranked Kenya leader in science production in Black Africa over the period 1992-1998. We would have liked to compare each country's total output to certain variables like the number of Universities, the number of researchers, the Gross Domestic Product Expenditure to Research and Development, etc.; but those data were not available, even throughout the UNESCO Institute of Statistics online database.

4.5.3. West African scientific output is extraverted

West Africa shared approximately one half its annual production with non-West African countries. The main partners are France, USA and United Kingdom both for the whole region and for individual countries. In consequence, Europe and America are the main partners at continent level. This finding confirms the result of many previous studies (e.g. Adams et al., 2010; Boshoff, 2009; Tijssen, 2007; Toivanen & Ponomariov, 2011). If colonial ties explained the ranking of France and the United Kingdom (Boshoff, 2009), Adams et al. (2010) justified the presence of the USA, a country with no former colonies in the region: "Often this is a consequence of researchers who have studied in the USA maintaining links with those research groups when they return home". The argument might also apply to Belgium and Germany.

The moderate international collaboration rate of the region over the period hides disparities among the Member States. The annual international collaboration rate of individual countries goes up to 100%, especially for the smallest producers like Sierra Leone, Liberia, Cape-Verde and Guinea-Bissau, probably mainly because they have no science base of their own. Nigeria the biggest producer has the lowest average rate (around 28%) over the period whereas the other countries' annual rate ranges from 69% to 96%. Some questions then arise: i) Is there a relation between the volume of production and the rate of international collaboration? ii) Is there a relation between the volume of production and the number of countries in international collaboration?

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[48] The two journals didn't appear in the JCR because Thomson Reuters proceeded to their removal after being aware of the publisher's unfair practices. Other titles from the same publisher should be sentenced the same way (See Harzing, 2012).

Table 4-11 summaries the international collaboration rate for each country considering different levels (West Africa, Africa, other continents, and World). We tested the association between the rate of international collaboration and the volume of output of a country; the result gave $r = -0.625$, $p < 0.01$, $\alpha=0.05$), leading to the conclusion that there is a moderate to strong negative association between the two variables: the less productive a country is in terms of scientific output, the greater is its dependence on international collaboration confirming Boshoff's (2009, 2010) conclusions.

Table 4-12 gives some social and economic data for West African countries. We tested whether there is an association between the volume of production and the number of partners countries and found that at the level of significance of 5%, there is a strong relationship between the two variables ($p < 0.1$, $\alpha = 0.05$, $r = 0.97$). Therefore, the more productive a country, the higher is its number of partner countries.

Table 4-11 West African countries' collaboration rates with the World and World's regions

Country	West Africa	Africa	America	Asia	Europe	Oceania	World
Benin	23.00	17.90	14.83	4.57	65.62	1.05	84.94
Burkina Faso	22.91	17.09	15.18	0.90	73.00	1.01	86.67
Cape Verde	1.92	9.62	23.08	5.77	76.92	1.92	92.31
Cote d'Ivoire	14.86	10.61	15.88	4.43	63.39	1.14	73.34
Gambia	16.23	15.42	22.41	7.51	80.93	5.27	89.05
Ghana	9.46	11.86	25.54	9.77	44.11	2.09	71.09
Guinea	30.71	17.01	22.41	9.13	64.73	4.15	84.65
Guinea Bissau	24.00	4.44	11.56	3.11	93.33	0.00	96.00
Liberia	12.24	16.33	55.10	8.16	38.78	2.04	85.71
Mali	18.52	15.28	44.35	7.31	50.66	1.41	88.87
Niger	31.40	17.06	20.65	8.53	57.51	0.85	85.49
Nigeria	2.59	6.29	9.74	4.82	13.24	1.07	28.42
Senegal	15.68	15.96	17.92	4.60	60.42	1.18	79.17
Sierra Leone	17.09	10.26	29.06	16.24	47.86	2.56	90.60
Togo	29.79	9.01	14.78	2.77	51.50	1.15	69.28
West Africa		17.95	30.08	10.92	68.50	2.60	49.66

Table 4-12 Basis social and economic statistics on West African countries (along with scientific output data)

Country	# partner countries	GDP per capita	HDI	Population (× 1000)	# papers per inhabitant	Rank			
						# partner countries	# papers	International collaboration	# papers / inhabitant
Benin	94	802	0.427	9,099	0.147	7	6	9	3
Burkina Faso	123	600	0.331	16,967	0.105	4	4	6	6
Cape Verde	30	3,798	0.568	500.6	0.104	14	14	2	7
Cote d'Ivoire	106	1,195	0.4	20,152	0.083	5	5	12	9
Gambia	88	625	0.42	1,776	0.555	9	8	4	1
Ghana	131	1,570	0.541	24,965	0.128	2	2	13	5
Guinea	93	502	0.344	10,221	0.024	8	11	10	13
Guinea Bissau	37	629	0.353	1,547	0.145	13	12	1	4
Liberia	28	281	0.329	4,128	0.012	15	15	7	15
Mali	101	669	0.359	15,839	0.076	6	7	5	10
Niger	87	374	0.295	16,069	0.036	10	9	8	12
Nigeria	149	1,452	0.459	162,470	0.096	1	1	15	8
Senegal	130	1,119	0.459	12,767	0.199	3	3	11	2
Sierra Leone	50	374	0.336	5,997	0.02	12	13	3	14
Togo	57	446	0.435	6,154	0.07	11	10	14	11

4.5.4. *West African countries ignored each other*

Collaboration within the region is negligible, confirming Onyancha and Maluleka (2011b) that “African countries contribute very little to each other’s knowledge production in terms of research articles”. Even though Nigeria is the local giant, it shared only 2.59% of its total production with other countries in the region. It didn’t act as the local North as South Africa did in the Southern region (Boshoff, 2009) by dominating their international relationships but preferred “co-linguists in East-Africa” (Adams, 2012). West African countries collaborated less with each other, less other with African countries and African regions than they did with France, the United Kingdom and the USA and other western countries. This result is the same as that of Boshoff (2010) and Jeenab and Pouris (2008). Hence, they cooperated more with developed countries than they did with developing ones. The statement of UNESCO Institute of Statistics (2005, p. 4) is confirmed. Indeed, Northern countries are wealthier and hence have more means to train scientists, equip laboratories, fund and promote research and improve its status. They are among global donors by the financial support they give annually to developing countries. In opposition, West African countries are categorized as developing countries; hence, they are poor and facing social and economic challenges that may hinder investments in research. Most African researchers have been trained in Western countries and then have kept relationships with their former colleagues or supervisors. Universities in developing countries have scientific cooperation agreements with Western higher education systems. Besides, Mêgnigbêto (2013e) reviewed the landscape of research in Benin, Ghana and Senegal and pointed out the common issues they are facing, among which i) lack of coordination between research programs and research activities, ii) lack of human and financial resources and equipment, iii) insufficiencies or inadequacies of funding and equipment. We may recall that, even some basic social, political and economic projects are financed by Western countries in developing countries. “This high international collaboration rate might indicate a structural dependence of African science, owing to the resources offered by advanced countries to help alleviate infrastructural and financial constraints are hampering many African science systems” (Toivanen & Ponomariov, 2011). In these conditions, science, technology and innovation are not easily prioritized. Boshoff (2009) underlined that Sub-Saharan Africa’s countries “are struggling to reach the target of allocating at least 1% of GDP to R & D” as they committed. We found no significant relation between volume of production and HDI on the one hand and volume of production and GDP on the other hand.

4.5.5. *Language and culture drive collaboration with African regions*

The main partners in Africa are South Africa in the South, Cameroon in the Central, Kenya and Tanzania in the East. All these countries belong to the big producers as identified by Adams et al. (2010) and Dahoun (1999). Cameroon is bilingual; the others are English speaking. So, with respect to their main African partners, the West

African countries are divided into three language-based groups: a French-speaking one, an English speaking one and a bilingual one (French and English). The bilingual group includes Benin, Burkina Faso, and Mali; the French speaking one is constituted by Senegal and Cote d'Ivoire.

While comparing Benin to Senegal and Ghana, Mêgnigbêto (2012) and Mêgnigbêto (2013e) noticed that Senegal published more in French than Benin. Particularly, Mêgnigbêto (2013e) attributed this phenomenon to the so-called Précarré français effects, that makes France, the former colonial power, to have privileged relations with some of its former colonies, due to economic or geostrategic interests. He stated that in Africa, the Précarré Français includes Cote d'Ivoire and Senegal in West Africa and Cameroon and Gabon in Central Africa. In order to check, we computed the percentage of papers each of these five countries (Benin, Senegal, Cote d'Ivoire, Burkina Faso and Mali) produced both in English and French. Cote d'Ivoire and Senegal produced in French 23.3% and 14.04% respectively; Benin, Burkina Faso and Mali produced respectively 10.71%, 11.43% and 8.47%. Cote d'Ivoire and Senegal produced in English 81.01% and 85.39% respectively; Benin, Burkina Faso and Mali produced respectively 90.19%, 89.64% and 92.19%. These statistics allow drawing the conclusion that the West African French speaking countries with a lower rate of publication in French, and hence a higher rate of publication in English, cooperate often with both English and French speaking countries, and conversely, those with a higher rate of publication in French and hence lower rate in English have fewer research relationships with African English speaking countries, instead. That explains the strength of their relations with Cameroon and the lack or insufficiency of ties with South Africa, Kenya or Tanzania. On the other hand, Benin, Mali and Burkina Faso have much strong ties both with Cameroon and South Africa, Kenya or Tanzania.

These analyses stressed the importance of language in driving collaboration. We might also notice that West Africa has no major relationship with the Northern Africa whose countries share culture and language (Adams et al., 2010). Culturally, West Africa is closer to Central, Southern and Eastern African than to the Northern Africa. The absence of ties between Western Africa and Northern Africa lends to the role of culture in collaboration driving.

4.6. Conclusion

The African continent has been examined by several scientometric studies but none exclusively was devoted to the West African region as defined by the African Union. We downloaded from Web of Science research papers with at least one co-author affiliated to any of the 15 countries of the region. Analyses focused on intraregional and international collaboration. Multi-authorship is gaining importance in the scientific output of West Africa. Nigeria is far the leader in scientific information producing regarding the total output. It has also the lowest international collaboration rate; in opposite, the other countries' rates are too high. West African scientific output is extraverted. Member States ignore each other while collaborating and seemed preferring other African region's local giant or former colonizers or western countries. Nigeria acts as a bridge towards African regions but not dominated individual countries’ production. Overall, language, colonial ties and culture drive collaboration in West Africa science.

It would be interesting to undertake further research to identify main institutions and cities that drive collaboration in the region. This study didn't find any effect of geographical proximity on the West Africa collaboration patterns. It didn't assess the impact of international collaboration in promoting publication by the impact it may have on citations received.

In order to strengthen intra-regional collaboration West African Member States should really allot 1% of their GDP to Research and Development as their committed to, help in equipping laboratories, recruit sufficiently qualified personnel and motivate them. They should also promote research product and status, help in setting up database at national and regional level to collect domestic research papers in order to measure their impact. Indeed, international databases have biases regarding developing or non-English speaking countries literature. Besides, in such countries, there exist scientifically valuable unpublished documents (Dahoun, 1999). West African countries and integration institutions should set up databases to index the scientific literature output in the region and encourage intra-regional collaboration.

5. Research collaboration between innovation actors in West Africa

The relationships between University, Industry and Government ensure the knowledge flow among the three actors and contribute to economic growth and hence to social and economic development. The objective is to study the collaboration network between University, Industry and Government in West Africa regarding scientific publishing and measure the extent to which this is helping progress toward welfare. This chapter is based on Mêgnigbêto (2013g).

5.1. Introduction

Traditionally, University teaches and researches, Industry commercializes the results as products, while Government sets up the regulatory framework, collects taxes and brings financial support. Knowledge-based economies need to sustain a high level of innovation due to the growing and strengthening of relations between university and firms, the effects of information and communication technologies and the emergence of networks and the need to reduce bureaucratic layers (Leydesdorff & Etzkowitz, 2001). The importance of the Triple Helix between University, Industry and Government has been stressed over the last decades. It ensures the knowledge flow among the three sectors and contributes to economic growth and hence to social and economic development. Through innovation and the renewal of the political economy and social structure, the Triple Helix is the key to knowledge-based economic development (Leydesdorff & Etzkowitz, 2001) because knowledge creation, flows and capitalisation are also important elements in stimulating economic development and contributes to regional growth (Mueller, 2006).

The African continent counts five regions based on cultural, historical, geographical and economic criteria:[49] the Northern (6 countries),[50] the Western (15 countries), the Central (9 countries), the Eastern (13 countries) and the Southern (10 countries). The West African Member States (in alphabetical order: Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo) together constitute the Economic Community of the West Africa States (ECOWAS), a regional economic integration organization. Three international language communities are distinguished in the region that are respectively French speaking, Portuguese speaking and English speaking.

[49] Resolution CM/Res.464 (XXVI) adopted by the African Unity Organization (now African Union) Council of Ministers meeting in its twenty sixth ordinary session in Addis-Ababa (Ethiopia) from 23 February to 1st March 1976. The countries list was updated in 2004.

[50] Even though Morocco is an African country and belongs to the North from a geographical point of view, it is not member of the African Union due to political reasons. Therefore, it is not considered in the African Union's classification. However, in this study, we included it into the Northern region.

The African Union, African regional economic communities and individual countries have recognized the role of science and technology for poverty alleviation and development (Toivanen & Ponomariov, 2011). In addition to regional institutions, other financial institutions, UNESCO and other international institutions support the formulation and implementation of science, technology and innovation policy. Article 27 of the ECOWAS Revised Treaty (ECOWAS Commission, 1993) clearly spells out that Member States shall ensure proper application of science and technology to the development of agriculture, transport and communications, Industry, health and hygiene, energy, education and manpower and the conservation of the environment, meaning that research should serve other sectors to develop and thus contribute to economic growth and social welfare.

A non-negligible number of papers dealt with the Triple Helix of University-Industry-Government relationships (Meyer, 2012; Meyer et al., 2014); even several special issues of journals were devoted to them (cf. Appendix 2); an entire book (Saad & Zawdie, 2011) dealt with the developing countries cases. Furthermore, an annual scientific conference has been holding;[51] and a journal, the Triple Helix Journal, was inaugurated in 2014. Only a few papers had sought to use bibliometric data to explore how the partnership between the three sectors is established (e.g Leydesdorff, 2003, 2008; Park et al., 2005). However, interests have been expressed for different areas recently, for example the OECD countries (Choi et al., 2015; Mêgnigbêto, under review, 2015c); South Korea (Kwon, 2011; Kwon et al., 2012; Mêgnigbêto, 2015a; Park & Leydesdorff, 2010), Japan, USA and some West European countries (Leydesdorff & Sun, 2009; Ye et al., 2013), West Africa (Mêgnigbêto, 2013g, 2014b, 2014c, 2015a, 2015b, China (Leydesdorff & Zhou, 2013) or Saudi Arabia (Shin et al., 2012).

In this chapter, our objective is to study the collaboration network between University, Industry and Government in West Africa regarding scientific publishing. Specifically, we will provide answers to the following research questions: i) What are the shares of University, Industry and Government in the West African scientific output? ii) To which extent do the three sectors collaborate in West African papers? iii) How strong are the sectorial relations in each of the West African Member State? iv) Which are the main actors of each sphere of the Triple Helix in the West Africa?

5.2. Political and sectorial governance within the ECOWAS

From their independence early 1960s to the end of the Cold War (end of 1980s), African States and hence almost all the ECOWAS Members States were ruled by single-party authoritarian regimes with central control and a state monopoly in all sectors of the economy. The fall of the Berlin Wall in 1989 has changed geopolitical strategies at the international level, mainly in Western countries, so most of the

[51] The 14th annual conference of the Triple Helix will be held in Germany in September 2016.

developing countries were forced to switch over to democracy with a liberalized political and economic system. West African regional institutions and Member States have recognized democracy as a system that sustains peace, stability, economic growth, social and economic development and a condition to regional integration (ECOWAS Commission, 2011b) and committed to "deepen and strengthen the democratic institutions using appropriate international standards" with an "ECOWAS of people" as target.

The ECOWAS adopted several sectorial policies among which the ECOWAS Policy on Science and Technology (ECOPOST) in 2012 and the West African Common Industrial Policy (WACIP) in 2010. Especially, the ECOPOST should help ECOWAS Member States to master all science fields required for the emergence of a scientific community able to compete and to exchange with the best research teams worldwide. Some of the problems West African science is facing are (cf. Mêgnigbêto, 2013e): i) lack of coordination between research programs and research activities, ii) lack of human and financial resources and equipment, iii) insufficiencies or inadequacies of funding and equipment. The WACIP envisions to "maintain a solid industrial structure which is globally competitive, environment-friendly and capable of significantly improving the living standards of the people by 2030" (ECOWAS Commission, 2010a, p. 4). The region's economic performance remains too inadequate (low GDP growth rate, extremely high inflation, etc.) to hope to have positive impact on the socio-economic conditions of the populations. The natural resources, especially agriculture products, are note valorised and the manufacturing industry contributes only 7% to the GDP. The high-tech sub sectors are not valorised. Even though West Africa has a vast wealth of untapped mineral resource (ECOWAS Commission, 2010a), these products locally undergo elementary processing. They are exploited by multinationals (from the Western countries often) that export for transformation into finished products. Major industries are limited in number and are local branches of multinationals. The ECOWAS industrial sector is still embryonic and therefore, not sufficiently diversified to produce a wide variety of intermediary and finished products. Over half of the industrial units in West Africa operate at less than 50 percent of their capacities (ECOWAS Commission, 2010a). The ECOWAS industrial output is insignificant; it represents only one percent of the World total output (ECOWAS Commission, 2010a, p. 4). Currently, no ECOWAS country has a robust and solid productive secondary sector to transform the national economy and join the global competition.

The weak performance of industry in West African Member States is explained by several factors. Funding for investment is scarce, access to efficient technologies (acquisition, maintenance) which are elements of differentiation and therefore of competitiveness is difficult, the national markets are inadequate and their integration is hampered by bureaucracy, customs and police harassment along the trade corridors (ECOWAS Commission, 2010b, pp. 24–25). Furthermore, the existing infrastructure is insufficient, because of excessively high costs and/or poor quality factors of production (electricity, water, etc.) and basic infrastructures (industrial areas, roads, railways, ICT, etc.). In consequence, even though the region is endowed with natural resources of which exploitation may contribute to its economic growth, two-thirds of the installed industries operate at less than 50 % of their capacities (ECOWAS Commission, 2010a). The ECOWAS vision 2020 (ECOWAS Commission, 2011b, p. 18) envisages a private sector "engine of growth and development" and an integrated regional production base developed by competitive private sector activities which provide production and distribution levers for deeper regional integration and development support by an efficient ECOWAS business body that promotes strong public-private partnership for generating wealth to sustain the development and property of the region. The vision also has the goal to promote active participation of the academic community in all issues related to the integration. Therefore, the ECOWAS vision 2020 expressed the willing of the region and shows that policy- makers are aware of the importance of the University, Industry and Government relationships for the development of both individual countries and the region.

Overall, democracy, which is recognized as a condition for economic and social development, has spread within the region recently. Even though there exist some political instabilities due to coup d'états and armed conflicts, democracy has installed a relatively peaceful environment that favours investment and development of the private sector, in comparison with the Cold War period.

5.3. Previous studies

5.3.1. The Triple Helix of University-Industry-Government relationships

The relationships between University, Industry and Government have gained attention in recent decades. They resulted from the transformation of the actors' role in the new economy. Etzkowitz and Leydesdorff (cf. Etzkowitz & Leydesdorff, 1995, 2000; Leydesdorff, 2012a) elaborated, on this basis, the Triple Helix concept that represents the necessary dynamics among the three sectors. If research activities exploit existing knowledge and produce new knowledge, the circulation of knowledge between innovation actors ensures its transformation into innovations. Innovation takes an important place in industrial development, economic growth and wealth production. There is a positive correlation between the levels of research and development activities and the level of absorption capacity and the pool of knowledge that can be exploited (Mueller, 2006). Hence, the knowledge flow between actors can indicate the level of development and the self-organization of the society or region.

5.3.2. Measuring the Triple Helix

Due to their importance in the economy, the Triple Helix relationships are object of indicators to allow performances measurement. Indicators have become a key aspect of works on University-Industry-Government relations and one third of publications on Triple Helix indexed in Thomson Reuters' Social Science Index deals with indicators (Meyer, 2012; Meyer et al., 2014). Some papers have proposed the use of indicators of science-technology interaction like patent citations, publication counts, patents counts, citations, co-authors and related indicators or inventor/author analysis (e.g. Acosta & Coronado, 2003; Callaert et al., 2006; Liang et al., 2012; Meyer et al., Utecht, 2003; Ranga et al., 2003; Van Looy et al., 2007); others are concerned with measuring information flows especially through entropy measures (e.g. Ivanova & Leydesdorff, 2014; Leydesdorff, 2003, 2008; Leydesdorff & Ivanova, 2014; Mêgnigbêto, 2014a); and some others have developed and applied indicators that go beyond patent counts and capture a lot of other relevant third mission activities of universities (e.g. Acosta et al., 2007; Baldini, 2006; Uranga et al., 2007).

The Triple Helix configuration can be depicted statically using social network analysis (Leydesdorff, 2003). Indeed, citation or patent analysis borrowed some indicators from social network analysis because citations establish links or relations between items that cite or are cited. Olmeda-Gómez et al. (2008) used social network analysis indicators like density, average degree, number of components, degree centralization, betweenness centralization, mean closeness score, diameter, and clustering coefficient to analyse research collaboration between University, Industry and Government. Considering the relations between University, Industry and Government as variables, Leydesdorff (2003) stated that the interacting fluxes generate probabilistic entropy and may be measured as an indicator of entropy. He then developed the mutual information or transmission as a measurement of the intensity of the relations among the Triple Helix. The resulting value can be negative, null or positive. A positive value means a centrally-controlled system; a negative value means a self-organised system, and a null value indicates absence of interactions. Therefore, the more negative the mutual information, the more non-coordinated and self-organised the system is, and the more positive the mutual information, the more centrally-controlled the system is. Leydesdorff and Sun (2009) extended the mutual information in three dimensions to four dimensions, where the fourth dimension, named 'foreign', groups papers co-authored with partner countries and Leydesdorff and Ivanova (2014) proposed the mutual redundancy as the positional counterpart of the relational communication of information. Muller (2006) proposed a model to measure the economic performance of an area; University-Industry relations are an input of that model[52].

5.3.3. Applying Triple Helix indicators

As indicated earlier, a non-negligible number of papers have been published dealing with the Triple Helix of University-Industry-Government relationships. For those having worked with bibliographic records, data sources are either Internet or

[52] Others are the annual economic growth rate, the growth rate of Total Factor Productivity (TFP), research and development activities in private enterprises, the generation of knowledge in universities, and entrepreneurship activity.

multidisciplinary bibliographic national or international databases like those of Web of Science. The mutual information was mainly used for three or four-dimensional systems (e.g. Khan & Park, 2011; Leydesdorff, 2003; Leydesdorff & Sun, 2009; Mêgnigbêto, 2013g; Ye et al., 2013). Social network analysis techniques were also used (Olmeda-Gómez et al., 2008). However, difficulties may arise while attributing labels to records based on affiliations data (Khan & Park, 2011, p. 2454). For example, an institution name only may not be sufficient enough to allow for categorization: as an illustration, the Chinese Academy of the Sciences (CAS) and the Chinese Academy of the Social Sciences (CASS) are considered either as public belonging to Government or University and consequently engendered the computation of two mutual information values for the county (Ye et al., 2013). Whatever the case is, globally, University publishes more than Government which, in turn, publishes more than Industry. University's ranking is due to the continuous influx of PhD students (Leydesdorff & Etzkowitz, 2001) and the publication mission of scholars. Because of these positions, University-Government output is the largest when bilateral relations among the sectors are considered, followed by University-Industry and Industry-Government research outputs. The joint collaboration University-Industry-Government is the smallest due to the effect of the double Boolean operator AND (Khan & Park, 2011; Leydesdorff, 2003; Leydesdorff & Curran, 2000; Leydesdorff & Sun, 2009). Globally, the relations between the three spheres depend on the political and economic conditions and also on the international environment.

Some studies have dealt with the University-Industry-Government relationships in African countries specifically (e.g. Etzkowitz & Dzisah, 2007 for the whole of Africa; Nwagwu, 2008 for Nigeria; and Taylor, 2004 for South Africa). In 2012, the Association of African Universities conducted a survey on University-Industry linkages in Africa (Ssebuwufu et al., 2012). But these studies didn't use any indicator; they neither studied the whole West African region nor used any bibliographic database.

5.4. Subjects and Methods

The elaboration of the Triple Helix of University-Industry-Government relationships thesis relies on collaboration between the three sectors. Of course, co-authorship provides a direct measure of collaboration (OECD, 2010, p. 98); collaboration may cover several aspects and not all collaboration yields publications (Katz & Martin, 1997). In this chapter however, we focus on research collaboration understood as co-authorship because its entails the tacit transfer of information and knowledge (Olmeda-Gómez et al., 2008). It has become an indicator for scientific collaboration measuring and is widely used in academia (Abbassi et al., 2012; Bordons & Gomez, 2000; Katz & Martin, 1997; Olmeda-Gómez et al., 2008).

We downloaded West African scientific publications data from Thomson Reuters' Web of Science over a ten-year period (2001-2010). The databases searched were Science Citation Index Expanded (SCI-EXPANDED), Conference Proceedings Citation Index-Science (CPCI-S), Conference Proceedings Citation Index- Social Science &

Humanities (CPCI-SSH) and Index Chemicus (IC). The search expression was *(cu=dahomey or cu=benin) or (cu=ivory coast or cu=cote ivoire) or cu=niger or cu=senegal or (cu=cabo verde or cu=cape verde) or cu=senegambia or cu=gambia or cu=ghana or cu=nigeria or cu=togo or cu=mali or cu=liberia or cu=sierra leone or cu=guinea or (cu=Burkina faso or cu=upper volta) or cu=guinea-bissau*. The 28,380 resulting records were downloaded into a bibliographic database managed with the CDS/ISIS[53] software application. Based on Leydesdorff's (2003) method for address assignment, we established a list of words or abbreviations to attribute a label 'University', 'Industry' or 'Government' to each address. We applied some adaptations to the three international language encountered in the region. Therefore, we coded a CDS/ISIS Pascal[54] programme that assigned each address the corresponding label. A record may contain many addresses; therefore, one record may have two or more different labels. The CDS/ISIS programme was also instructed to read the countries' name from the addresses and automatically add the associated two characters ISO codes to the label. Non West African countries were given the unique identifier ‘ZZ’. Therefore, in the inverted file, a university in Benin appears under the label UNIV-BJ, an enterprise in a non-West African country appears under ZZ-INDU.

The CDS/ISIS search function operates mainly over the inverted file that contains “searchable terms” as previously defined by the database administrator upon a field. It admits the Boolean operators OR symbolized by the sign + (plus), AND symbolized by the character * (star) and NOT symbolized by the character ^ (circumflex). We run searches over the CDS/ISIS database using key-words composed of each country names and Triple Helix actors' codes. For examples, the searches expressions (1) to (7) were conducted for Benin:
(1) UNIV-BJ: retrieves all records university in Benin authored;
(2) INDU-BJ: retrieves all records industry in Benin authored;
(3) GOV-BJ: retrieves all records government in Benin authored;
(4) UNIV-BJ * INDU-BJ retrieves all records university and industry in Benin co-authored;
(5) UNIV-BJ * GOV-BJ retrieves all records university and industry in Benin co-authored;
(6) INDU-BJ * GOV-BJ retrieves all records industry and government in Benin co-authored;
(7) UNIV-BJ * INDU-BJ * GOV-BJ retrieves all records university, industry and government in Benin co-authored.

[53]CDS-ISIS is text database management software developed and distributed by UNESCO (1989a).
[54] CDS/ISIS provides a programming language “designed to develop CDS/ISIS applications requiring functions which are not readily available in the standard package” (UNESCO, 1989b). This programming language enables users to extend functions of the standard package, to make it more robust and in order to meet users’ specific needs (Mêgnigbêto, 1998).

Finally, the contribution of each actor was computed as follows (according to the Venn diagram in Figure 7-1):
U = (1) – (4) – (5) + (7): number of publications university only authored;
I = (2) – (4) – (6) + (7): number of publications industry only authored;
G = (3) – (5) – (6) + (7): number of publications government only authored;
UI = (4) – (7): number of publications university and industry only co-authored;
UG = (5) – (7): number of publications university and government only co-authored;
IG = (6) – (7): number of publications industry and industry only co-authored;
UIG = (7): number of publications university, industry and government co-authored.

Such searches and computation were run for individual countries and then for the whole region.

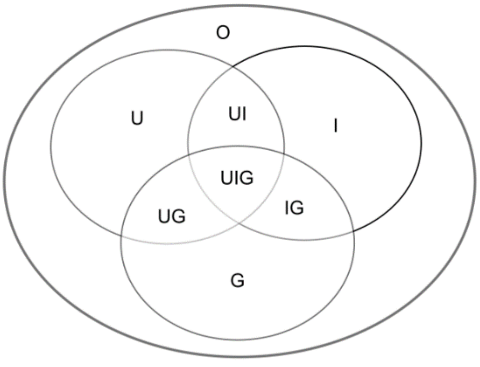

Figure 5-1 . Cardinalities in a three dimensional system S = (U, I, G)

Furthermore, a second CDS/ISIS programme was used to generate the social network file for the joint collaboration for analysis with Pajek, a software application for large social network analysis (de Nooy, Mrvar, & Batagelj, 2011). The print service of CDS/ISIS was used to output some data into text file for statistical analyses. Finally, we used the programme created by Leydesdorff (available at http://www.leydesdorff.net/th2/index.htm) to compute the mutual information between University, Industry and Government.

We assigned labels to 84.37% of addresses, 96.20% of records and 88.4% of the West Africa-based addresses and 90% of the records if West Africa alone is taken into account (Table 5-1). This identified a total of 13,162 institutions of which 5,161 (38%) are based in West Africa.

Table 5-1. Repartition of records and addresses per Triple Helix sphere (West Africa).

	All institutions				West African institutions			
	Record		Address		Record		Address	
	#	%	#	%	#	%	#	%
University	23,503	82.82	44,873	56.53	19,143	67.45	27,277	61.32
Industry	304	1.07	321	0.40	145	0.52	147	0.33
Government	11,661	41.09	21,778	27.43	8,994	31.69	11,963	26.89
Not Classified	1,078	3.80	12,409	15.63	2,862	10,08	5,099	11.46
Total	28,380	100	79,381	100	28,380	100	44,486	100

5.5. Results

It should be borne in mind that numbers are very low for many sectors and that this analysis represents the emergence of research structure in a group of countries with historically low levels of R&D investment compared to e.g. Europe. This analysis therefore provides both a case study of the present and a reference benchmark for the future.

5.5.1. Production per Triple Helix sphere

Over the period 2001 to 2010, there were university addresses on 19,145 (67.45%) papers, Industry addresses on 145 (0.52%) papers and Government addresses on 8,994 (31.09%) papers (Table 5-2). Industry's 145 papers over a ten-year period is an average of 15 papers per year for all the 15 West African countries and 1 paper per year per Member State. The U and I shares are trending upwards whereas the G one is trending downwards Figure 5-2). This doesn't mean a diminishing Government output, but rather a growth less than that of the total production of the region (Table 5-2). It is clear however that the private sector contributes to the knowledge exchange marginally in West Africa, regarding scientific publishing.

Analysis at the level of individual countries shows disparities regarding each sphere's contribution to the research output (cf. Table 5-3). Industry was absent completely in the scientific output of six countries (Benin, Gambia, Guinea Bissau, Liberia, Mali and Niger). In Nigeria and Ghana, it produced 101 papers and 30 papers respectively, ranking these two countries first and second respectively. However, the highest percentage share of industrial output is registered in Cape Verde (21.4%) due to the country's low total output (52 papers). University is the biggest science producer in Ghana (56.85%), Nigeria (87.80%) and Togo (51.96%), and Government is the prime producer elsewhere. This result may have been influenced by the categorization we did, because hospitals were classified as belonging to Government.

Table 5-4 computes the specialisation indexes[55] of the Triple Helix spheres in West Africa using Frascati Manual (OECD, 2007) categories with the whole West Africa region as reference. While Government specializes in *Health and medical sciences* (certainly a consequence of the classification of hospitals into G), University

[55] The specialization index is an indicator of the intensity of research of a given geographic or organizational entity (e.g., a country) in a given research area (domain, field) relative to the intensity of the reference entity (e.g., the world) in the same research area. An index value above 1 means that a given entity is specialized relative to the reference entity, while an index value below 1 means the opposite, an index around 1 means a neutral production. The specialization index is the ratio between the share of an actor in a field reported to the reference area's total output in the same field and the share of the actor to the total production of the reference area.
http://shrf.ca/saskatchewan-health-research-foundation/Advancing%20Knowledge

dominates the *Social sciences* and Industry *Engineering and technology*. The pattern is therefore very much as might be expected.

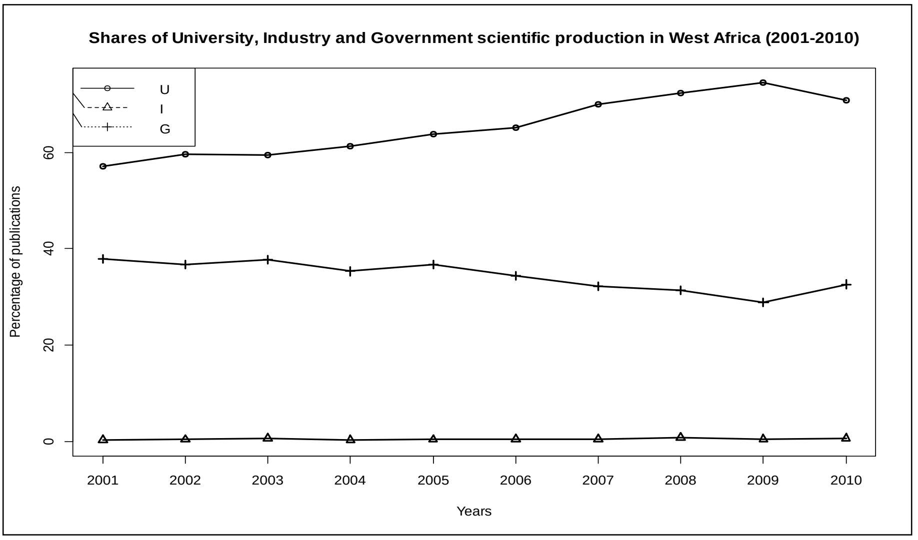

Figure 5-2 Percentage shares of U, I and G in the West African scientific publishing

Table 5-2. West African scientific output per Triple Helix actor

	U	I	G	UI	UG	IG	UIG
2001	780	3	447	1	103	1	0
2002	884	6	454	0	129	1	0
2003	925	8	482	3	156	1	0
2004	1,011	4	463	2	151	0	0
2005	1,410	6	657	3	252	1	0
2006	1,507	6	644	4	238	0	2
2007	2,086	7	735	7	327	1	0
2008	2,356	10	747	13	400	4	3
2009	2,756	7	739	11	427	1	1
2010	2,684	12	926	12	497	2	2
Total	16,399	69	6,294	56	2,680	12	8

Table 5-3. West African countries scientific output per Triple Helix actor

Country	U	I	G	UI	UG	IG	UIG
Benin	548	0	668	0	93	0	0
Burkina Faso	484	1	1,114	0	164	0	0
Cape Verde	14	3	26	0	1	0	0
Cote d'Ivoire	784	1	808	0	144	0	0
Gambia	7	0	208	0	5	0	0
Ghana	1,821	30	1,371	7	393	5	0
Guinea	49	3	168	0	11	0	0
Guinea Bissau	16	0	185	0	13	0	0
Liberia	14	0	26	0	4	0	0
Mali	517	0	569	0	85	0	0
Niger	196	0	304	0	16	0	0
Nigeria	13,669	101	2,683	53	1339	14	7
Senegal	1,062	3	1,172	0	180	0	0
Sierra Leone	48	2	60	0	8	0	0
Togo	225	1	191	0	26	0	0

Table 5-4. Specialization indexes of the Triple Helix spheres in West Africa

Field of Science	U		I		G	
	#	Index	#	Index	#	Index
1. Natural sciences	6,504	1.04	67	1.44	2,313	0.79
2. Engineering and technology	3,268	1.27	38	1.97	508	0.42
3. Health and medical sciences	8,344	0.89	8	0.11	5,650	1.28
4 Agricultural sciences	2,260	0,90	20	1.07	1,287	1.09
5. Social sciences	573	1.46	4	1.37	122	0.66
6. Humanities	56	0.85	1	2.03	22	0.71
Total	19,143		143		8,994	

5.5.2. Collaboration between the Triple Helix's spheres

Because the total output of Industry is negligible, its breakdown per year yields weak trends. Because of this, collaboration between Industry and Government, Industry and University and joint collaboration between the three spheres is difficult to index. Industry collaborates however, more with University (UI) than Government (IG); the University-Government relations output the highest number of bilateral publications. All the three curves show an increasing trend and the collaboration indexes, that is the percentage of papers that is authored in collaboration, are also trending upwards (Figure 5-3 and Figure 5-4).

At the level of individual countries, all the 15 Member States have data on University and Government collaboration; but only two countries have data on Industry and

University collaboration: Ghana with 7 papers representing 0.23% of the Ghanaian total output and 33.33% of the country's industrial output, and Nigeria with 53 papers –0.34% of the Nigeria total and 51.43% of the Nigerian industrial output. These countries are the only ones that had publication collaboration between Industry and Government. The percentage share of University-Government relations got its maximal value in case of Guinea Bissau (81.22% of the country's total output) perhaps due to the lower level of the latter or to the weaknesses in the Bissau-Guinean universities research system. The joint collaboration between University, Industry and Government is marginal; 9 publications spread thinly across environment and health categories. 7 of them have Nigerian-based co-authors; the remaining two records have co-authors based in different West African countries.

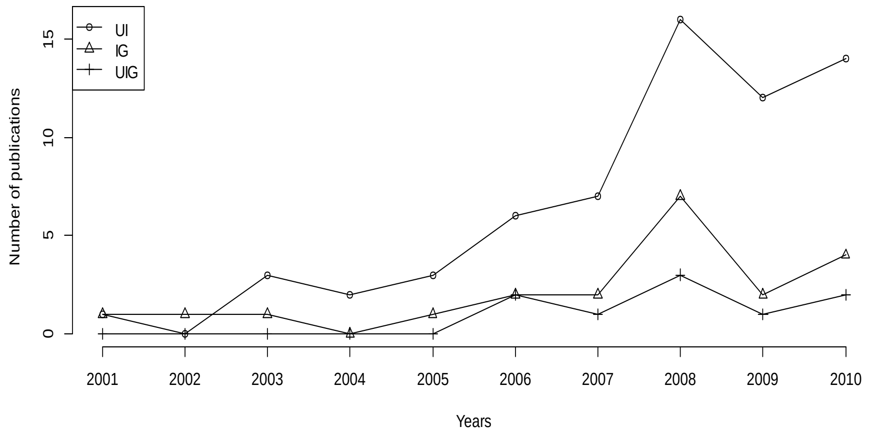

Figure 5-3 UI, IG and UIG output in West Africa

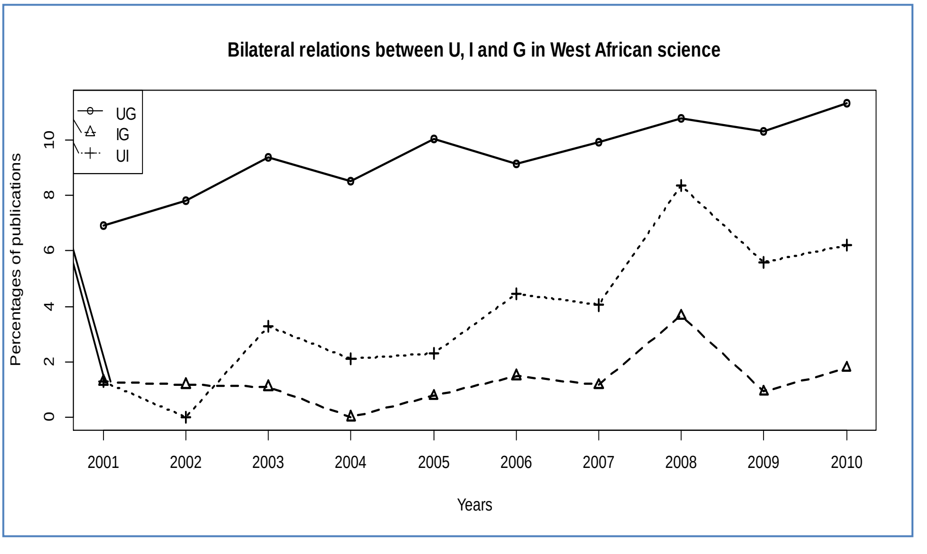

Figure 5-4 Bilateral collaboration indexes between U, I, and G in West Africa

5.5.3. The level of synergy

We used the mutual information indicator to evaluate the level of self-organization or central control in an economy. We calculated the related value for the West African region over the period 2001-2010. The values are all negatives, ranging from –13 to –32 millibits, with an average of –19 millibits[56] (Table 5-5) showing the weaknesses of information exchange between University, Industry and Government in West Africa from the perspective of research publishing as indicator of collaboration. Annual transmissions are negative indicating synergy among actors; in other words, the system is not centrally controlled over the studied period of times; however the interactions between actors are too low and cannot ensure better knowledge circulation. Indeed, transmission varies from -13 to -32 millibits. At the level of individual countries, Cape Verde has the highest transmission (- 217 millibits) and the six countries with 0 output for industrial sector has a null transmission (Table 5-6).

5.5.4. The industrial research network

The production of Industry is very small; its co-publication with the other sectors is even smaller due to the Boolean operator effect. The 145 industrial records contained 107 institutions. The visualization of the network reveals 23 components of which 20 have very few members. We deleted these and focused on the remaining three with 33, 15 and 9 actors. Each institution name was prefixed with its country's ISO two characters code. The first two components group together Nigeria-based institutions, and the third Ghana-based ones. The numbers are extremely low and connectedness is therefore, weak. As a result, indicators of centrality are probably not yet informative. Shell Nigeria, University of Ibadan, University of Lagos and Rivers State University dominate the larger Nigerian component (Figure 5-5) while in the smaller one, the leaders are University of Calabar, Mobil, University of Maiduguri, Innovation Biotech Ltd, and University of Jos. In the Ghana-based component, University of Ghana is a central actor.

[56] The 'maximum' value of the mutual information, in this case, is –2,807 millibits.

Table 5-5. Mutual information (in millibits of information) of the West African region

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2001-2010
Mutual information	-16.631	-27.457	-32.054	-18.098	-18.384	-20.216	-15.719	-18.110	-12.637	-19.390	-18.652

Table 5-6. Mutual information (in millibits of information) of the West African countries.

Country	Benin	Burkina Faso	Cape Verde	Cote d'Ivoire	Gambia	Ghana	Guinea	Guinea Bissau
Mutual information	0.00	-5.503	-216.902	-5.731	0.00	-47.321	-65.955	0.00
Country	Liberia	Mali	Niger	Nigeria	Senegal	Sierra Leone	Togo	
Mutual information	0.00	0.00	0.00	-31.148	-11.011	-86.739	-18.175	

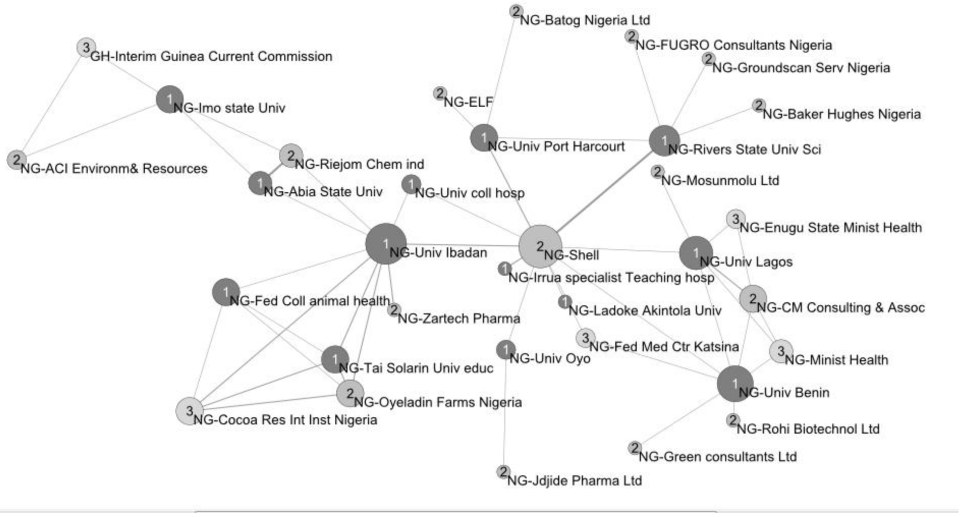

Figure 5-5 The largest Nigeria-based industrial relations
Note: 1 = University – 2 = Industry – 3 = Government.

5.6. Discussion

University is the biggest information producer, but Industry so far contributes little to the West African scientific production. Globally, University produced more than Government which, in turn, produced more than Industry. This conclusion conforms to the results of Khan and Park (2011) as regarding web pages and also those of Leydesdorff (2003) and Leydesdorff and Sun (2009). The joint collaboration between the three spheres is negligible industrial sector's very small scientific output and the effect of the double Boolean operator AND. In West African countries, as in other developing countries, the economy is characterized by an important informal sector – 60% of the global added value (ECOWAS Commission, 2010a) – that weakens the formal sector. Even though the industrial sector contributes 30.3 % to the regional Gross Domestic Product, this is still weak, in comparison to the emerging countries (ECOWAS Commission, 2010a) and is focused on low-technology areas to sustain a developing economy.

The negativity of the mutual information between University, Industry and Government is however a favourable point, although its absolute size is low. It indicates that the innovation system is changing from a state-controlled to a self-organized one, probably due to the advancement of liberal democracy within the region. We compared the percentage share of the industrial sector in the West African scientific output to that of the BRICS countries. Whereas it is only 0.5% in case of West Africa, its values are 2.4% in Brazil, 1.62% in Russia, 3.13% in India and 11.07% in China (data taken from Leydesdorff, 2003); mutual information values are respectively –27.11, –58.16, –109.5, –19.45/–36.01 and –21.35 millibits (data taken from Ye et al., 2013) whereas it ranges from –13 to –32 millibits in case of West

Africa with an average of −19 millibits. Because the more negative the mutual information the more synergy there is between University, Industry and Government, these statistics meant that compared with the West African region, the BRICS countries have a higher synergy within their University-Industry-Government relationships when publications are taken as unit.

The West African universities and governmental bodies also collaborated with non-West African industrial sector ('foreign Industry' from a West African perspective); but the outcome is also marginal (16 records) even though twice the number of records Government and University shared with the local Industry. Globally, the industrial sector contributed 304 papers to the West African output, of which 167 are authored by 'foreign Industry'. It should be underlined that the foreign Industry doesn't share any publication with the local Industry. The weak output of Industry in the region is explained by the factors that are hindering the industrial development and referred to previously. Particularly, the vast wealth of untapped mineral resources the region is endowed with locally, undergo elementary processing; they are exported and transformed into finished products that are sold back to African people. Consequently, the local Industry role is reduced to extracting and exporting resources; it doesn't need to explore the local market, to produce to satisfy local consumers. In other words, local Industry does not have the opportunity to do research and innovate: West Africans' 'taste' doesn't matter while thinking innovation because products are conceived abroad. Therefore, much research is not undertaken locally, but in the countries where products are transformed.

5.7. Conclusion

The publication data of West Africa over the period 2001-2010 indexed in Thomson Reuters' Web of Science was analysed. We focused on University, Industry and Government relationships both at regional and individual country levels. Results showed that as regarding the number of papers, University is ranked first, Government second and Industry third. The industrial sector's share to the region's output is marginal. University and Government have relations in all the West African countries, but Industry exhibits relations with Government or University in Nigeria and Ghana only. Relations between all the three sectors occurred only in Nigeria. The mutual information is weak illustrating the weakness in the information flow between the three actors in the region, when research output is concerned. The industrial institutional research network distinguished three groups among which two are Nigeria-based and one Ghana-based. The Triple Helix thesis is that the University-Industry-Government relations lead to competitiveness and economic growth (Leydesdorff, 2003; Mueller, 2006). According to Mueller (2006) the level of research and development products absorption determines the level of development. The data we treated are too weak and research collaboration is not limited to publishing only; therefore, no conclusion could be drawn about information flow within the Triple Helix system and the level of development in West Africa.

6. The transmission power as an indicator of the Triple Helix

In this chapter, we analyse the complex system of the Triple Helix of University-Industry-Government relationships from the information theory point of view. We show that an information source composed with n random variables may be split into 2^n or $2^n - 1$ "states"; therefore, one could compute the maximum entropy of the source. We derive the efficiency and the unused capacity of an information source. We demonstrate that in more than two dimensions, the transmission's variability depends on the system configuration; thus, we determine the upper and the lower bounds to the mutual information and propose the transmission power as an indicator of the Triple Helix of University-Industry-Government relationships. Then, we find out two- and three-dimensional configurations where the mutual information reaches its bounds and compute efficiency, unused capacity and transmission power for such systems as well as for some particular cases.

This chapter is based on Mêgnigbêto (2014a) and Mêgnigbêto (2014e).

6.1. Introduction

Indicators have become a key aspect of works on University-Industry-Government relations (Meyer, 2012; Meyer et al., 2014). Leydesdorff (1991) introduced Shannon's (1948) information theory into research collaboration network analysis. Later on, the transmission or mutual information was proposed as an indicator of the relations between University, Industry and Government (Leydesdorff, 2003) based on the notion of entropy introduced by Shannon (1948, p. 394) in his *Mathematical theory of communication*. Ivanova and Leydesdorff (2014) on the one hand, and Leydesdorff and Ivanova (2014) on the other hand, dealt with the mutual redundancy. So, research collaboration, in general, and University (U), Industry (I) and Government (G) research relations, in particular, may be measured using information theory tools as stated by von Bertalanfy (1973, p. 94). The mutual information is interpreted as the extent to which a system is controlled by an actor, or self-organized and the mutual redundancy as the positional counterpart of the generation of uncertainty in relational communications. The mutual information is also called 'configurational information' because it results from the system's configuration; it means that it does not depend on one particular variable (Leydesdorff, 2003, 2008; Leydesdorff & Sun, 2009, p. 780). In more than two dimensions, the mutual information is a signed measure: it may be negative, null or positive (Leydesdorff, 2008, 2010a; Leydesdorff & Ivanova, 2014; Yeung, 2001, 2008); it is not a Shannon-type information (Krippendorff, 2009a, 2009b; Leydesdorff & Ivanova, 2014). According to Leydesdorff (2003), in more than two dimensions, if the mutual information is positive, it indicates a centrally coordinated system; if it is negative, it indicates synergy or the level of self-organisation within the system. A null mutual information means independence of variables and is interpreted as absence of interactions between variables; however, Krippendorff (2009a, 2009b) warned that the mutual information could not be used as indicator of unique interactions in complex systems.

Several studies used the mutual information to analyse University-Industry-Government relations in different areas (e.g. Khan & Park, 2011; Leydesdorff, 2008; Leydesdorff & Sun, 2009; Mêgnigbêto, 2013g; Ye et al., 2013). The mutual information is a scalar (Ivanova & Leydesdorff, 2014); it has lower and upper bounds that, like its value, depend on the system's configuration. Therefore, it may be difficult, even impossible to compare a system to another or the same system over times with respect to this indicator. For example, how one can compare two systems S_1 and S_2 if the upper bound to the transmission in one system (say S_1) is lower than the lower bound to the transmission of the other system (say S_2)? We argue that the mutual information is not sufficient for comparison purposes. Doing so may lead to misinterpretation or bias. In this chapter, we first show that one can split the entropy of an n-dimensional system into 2^n additive parts, each engendered by an atom[57] from the sets related to the considered variables; we derive efficiency and unused capacity to characterise a Triple Helix of University-Industry-Government relationships system. We propose the transmission power, which relates the absolute value of the transmission to its lower or upper limits.

6.2. Methodological background

Let us assume that an event occurs with the probability p. (Shannon, 1948, p. 394) defined the associated entropy as

$$\mathrm{H} = -\mathrm{p} \times \log_2 \mathrm{p} - (1 - \mathrm{p}) \times \log_2 (1 - \mathrm{p}) \qquad (6\text{-}1)$$

where $\log_2$ is the logarithm to the base 2; the entropy may however be computed to other bases e. g. 3, 4, etc.). More generally, if $X = (x_1, x_2, \dots, x_n)$ is a random variable and its components occur with the probabilities $p_1, p_2, \dots, p_n$ respectively, then the entropy generated by X is (Shannon, 1948; Shannon & Weaver, 1949, p. 14)

$$\mathrm{H_X} = -\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{p_i} \times \log_2 \mathrm{p_i} \qquad (6\text{-}2)$$

For two random variables X and Y (two dimensions), the joint entropy H_{XY} is

$$\mathrm{H_{XY}} = \mathrm{H_X} + \mathrm{H_Y} - \mathrm{T_{XY}} \qquad (6\text{-}3)$$

T_{XY} is called mutual information or transmission. It is lower than or equal to H_{XY}.

$$\mathrm{T_{XY}} = \mathrm{H_X} + \mathrm{H_Y} - \mathrm{H_{XY}} \qquad (6\text{-}4)$$

[57] An atom is a subset of a set with the maximum number of elements so that the intersection of any couple of atom is empty and the union of all the atoms of a set gives the set itself ((cf. Yeung, 2001, p. 96, 2008, p. 50).

In case of three random variables X, Y and Z (three dimensions), the joint entropy is (cf. Leydesdorff, 2003; Leydesdorff & Ivanova, 2014):

$$H_{XYZ} = H_X + H_Y + H_Z - T_{XY} - T_{XZ} - T_{YZ} + T_{XYZ} \tag{6-5}$$

and the transmission is

$$T_{XYZ} = H_X + H_Y + H_Z - H_{XY} - H_{YZ} - H_{XZ} + H_{XYZ} \tag{6-6}$$

6.3. Splitting a composed source into its states

An information source is a random variable that produces symbols (Cover & Thomas, 2006; Le Boudec, Thiran, & Urbanke, 2013, p. 8; Mori, 2006, p. 16; Shannon, 1948, p. 392). An information source may also be composed of two or more random variables. Assume that the values of the random variable are "0, the source doesn't produce" and "1, the source produces". We build, by this way, the alphabet A= {0,1} of a source with only one random variable; its cardinality is 2. If the source is composed with two random variables, then the alphabet becomes A×A = A^2={0,1}×{0,1} = {(0,0),(0,1),(1,0),(1,1)}; its cardinality is 2^2 = 4. Each element of the source's alphabet constitutes an event. Then, the entropy of the source is:

$$H_{XY} = -p(0,0) \times \log_2 p(0,0) - p(0,1) \times \log_2 p(0,1) - p(1,0) \times \log_2 p(1,0) - p(1,1) \times \log_2 p(1,1) \tag{6-7}$$

For example, the probability distribution of a couple of variables X and Y, each with the alphabet A = {0, 1} is given in Table 6-1.

Table 6-1. Joint probability density of two random variables X and Y each with alphabet {0, 1}

Y X	0	1	p(X)
0 1	p(X = 0,Y = 0) p(X = 1,Y = 0)	p(X = 0,Y = 1) p(X = 1,Y = 1)	p(X = 0) p(X = 1)
p(Y)	p(Y = 0) = p(X = 0,Y = 0) + p(X = 1,Y = 0)	p(Y = 1) = p(X = 0,Y = 1) + p(X = 1,Y = 1)	p(X = 0) + p(X = 1) = p(Y = 0) + p(Y = 1) = 1

The probability that neither X nor Y produce is p(X = 0, Y = 0); the probability that X does not produce but Y does is p(X = 0, Y = 1); the probability that X produces but Y does not is p(X = 1, Y = 0); the probability that both X and Y produce is p(X = 1, Y = 1).

It can be seen in Table 6-1 that:

$$p(X = 0) = p(X = 0, Y = 0) + p(X = 0, Y = 1) \tag{6-8}$$

$$p(X = 1) = p(X = 1, Y = 0) + p(X = 1, Y = 1) \tag{6-9}$$

$$p(Y = 0) = p(X = 0, Y = 0) + p(X = 1, Y = 0) \tag{6-10}$$

$$p(Y = 1) = p(X = 0, Y = 1) + p(X = 1, Y = 1) \quad (6\text{-}11)$$

$$p(X = 0) + p(X = 1) = p(Y = 0) + p(Y = 1) = 1) \quad (6\text{-}12)$$

$$p(X = 0, Y = 0) + p(X = 0, Y = 1) + p(X = 1, Y = 0) + p(X = 1, Y = 1) = 1 \quad (6\text{-}13)$$

Therefore, entropies follow:

$$H_X = -p(X = 0) \times \log_2 p(X = 0) - p(X = 1) \times \log_2 p(X = 1) \quad (6\text{-}14)$$

$$H_Y = -p(Y = 0) \times \log_2 p(Y = 0) - p(Y = 1) \times \log_2 p(Y = 1) \quad (6\text{-}15)$$

$$H_{XY} = -p(X = 0, Y = 0) \times \log_2 p(X = 0, Y = 0) - p(X = 0, Y = 1) \times \log_2 p(X = 0, Y = 1) - p(X = 1, Y = 0) \times \log_2 p(X = 1, Y = 0) - p(X = 1, Y = 1) \times \log_2 p(X = 1, Y = 1) \quad (6\text{-}16)$$

Using the Venn diagram, the events of which probabilities are depicted in Equation 6-16 may be represented as in Figure 6-1 where E stands for the universal set, X the subset engendered by the random variable X and Y that of Y.

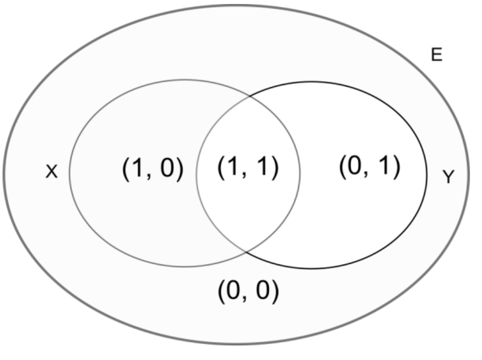

Figure 6-1 Events in case of two random variables with alphabet {0, 1}

In case of three random variables X, Y and Z, each with the alphabet A = {0, 1}, the source's alphabet becomes A^3 = {(0, 0, 0), (0, 0, 1), (0, 1, 0), (0, 1, 1), (1, 0, 0), (1, 0, 1), (1, 1, 0), (1, 1, 1)}. The cardinality is 8. The Venn diagram that corresponds is represented in Figure 6-2.

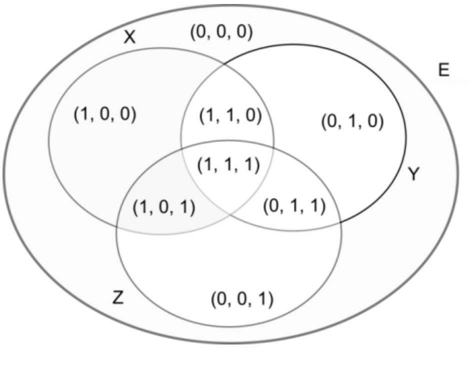

Figure 6-2 Events in case of three random variables with alphabet {0, 1}

Here, the entropy of the system is:

$$\mathrm{H_{XYZ}} = -\mathrm{p}(0,0,0) \times \log_2 \mathrm{p}(0,0,0) - \mathrm{p}(0,0,1) \times \log_2 \mathrm{p}(0,0,1) - \mathrm{p}(0,1,0) \times \log_2 \mathrm{p}(0,1,0) - \mathrm{p}(0,1,1) \times \log_2 \mathrm{p}(0,1,1) - \mathrm{p}(1,0,0) \times \log_2 \mathrm{p}(1,0,0) - \mathrm{p}(1,0,1) \times \log_2 \mathrm{p}(1,0,1) - \mathrm{p}(1,1,0) \times \log_2 \mathrm{p}(1,1,0) - \mathrm{p}(1,1,1) \times \log_2 \mathrm{p}(1,1,1)$$
(6-17)

The subsets depicted in Figure 6-1 and Figure 6-2 correspond to the atoms engendered by the two or three subsets of the universal set generated by the considered two or three initial random variables (cf. Yeung, 2001, p. 95, 2008). Each element of the source's alphabet constitutes an event and relates to a subset in these figures. The equation of the joint entropy (Equation (6-17)) reveals them as states of the same source (Mori, 2006; Shannon, 1948). The alphabet of the source is the set of its "finite number of possible states" (cf. Shannon, 1948, p. 389). Therefore, the number of "possible states" of a source composed with two such random variables is $2^2 = 4$ and equals $2^3 = 8$ if the number of random variables is three. More generally, if a source is composed with n random variables each with the alphabet {0, 1}, the number of events the joint distribution of the n variables engendered is 2^n.This result conforms to the 2^n atoms generated by the two or three subsets of the universal set engendered by the two or three initial random variables (cf. Yeung, 2001, p. 95, 2008).

6.4. Consequences: deriving efficiency and unused capacity

According to the development in the previous section, we may split a composed source into its states. Hence, we can compute its maximum entropy (Cover & Thomas, 2006; Mori, 2006; Shannon, 1948; Yeung, 2001, 2008).

$$H_{max} = \log_2 M \qquad (6\text{-}18)$$

where M is the number of independent random variables in the system or the number of states of the source. The maximum entropy is the upper limit of the entropy of the system H_S. It indicates the system's information production capacity. As Equation (6-18) shows, it do not depend on any data produced by the system but only on the number of independent random variables; it means that for any system of the same dimensionality, H_{max} has the same value. In general, the entropy of the system, H_S is lower than H_{max}; that means that a part of the system's information production capacity may be used and the other not. Therefore, one could compute the efficiency and the unused capacity of the system.

We define the efficiency of a system as the fraction of its information production capacity that is really produced.

$$\eta = \frac{\mathrm{H_S}}{\mathrm{H_{max}}} \qquad (6\text{-}19)$$

H_S and H_{max} are all positive and H_S is lower than or equal to H_{max}; therefore, η ranges from 0 to 1. η is dimensionless and could also be expressed as percentage.

H_{max}– H_S represents the unused capacity of the system. The relative unused capacity is the unused capacity reported to the maximum entropy. It is the fraction of the capacity of the system that is not used for information production. ρ is the complement to 1 of the efficiency. ρ is dimensionless and could also be expressed as percentage.

$$\rho = \frac{\mathrm{H_{max}} - \mathrm{H_S}}{\mathrm{H_{max}}} \quad \text{or} \quad \rho = 1 - \eta \tag{6-20}$$

6.5. Transmission power

The mutual information or transmission is the quantity of information common to the random variables in the system (Shannon, 1948, p. 410). In two dimensions, it measures the system's variables dependence on each other (Batina et al., 2011); it is always null or positive (Cover & Thomas, 2006; Shannon, 1948; Yeung, 2001, 2008) and increases with the dependence between the components of the considered variables (Arellano-Valle et al., 2013). In more than two dimensions, mutual information is a signed measure (Leydesdorff & Ivanova, 2014; Yeung, 2001, p. 103, 2008); it may be null, positive or negative (Cover & Thomas, 2006; Leydesdorff, 2003, 2008, Yeung, 2001, p. 103, 2008).

We define the transmission power as the fraction of the maximum value of the transmission devoted to information sharing in the system. It represents the share of the "total configurational information" really produced in the system. In other words, it measures the efficiency of the mutual information and may be interpreted as the strength of the transmission, of the variables dependence or of the synergy, or the strength of the information flow within the system or between the system's actors. It may help in measuring the level of synergy within the system or among variables or the pressure or the control exerted within the system.

In two dimensions, the transmission power formula is:

$$\tau = \frac{\mathrm{T_{XY}}}{\mathrm{H_{XY}}} \tag{6-21}$$

Due to the possible change of the sign of the transmission in more than two dimensions and the duality in its interpretation, we distinguish between two types of transmission power τ: τ_1 when the mutual information is negative, and τ_2, when it is positive. In the first case, the 'maximum' value the transmission may reach is H_{XYZ} – H_X – H_Y– H_Z and H_{XYZ} in the second case (Appendix 3). It follows that

$$\tau = \begin{cases} \tau_1 = \frac{T_{XYZ}}{H_{XYZ} - H_X - H_Y - H_Z} \text{ if} T_{XYZ} < 0 \\ \tau_2 = \frac{T_{XYZ}}{H_{XYZ}} \text{ if} T_{XYZ} > 0 \\ 0 \text{ if} T_{XYZ} = 0 \end{cases} \quad (6\text{-}22)$$

In any case, $0 \leq \tau \leq 1$. τ_1 indicates the level of synergy and τ_2 the extent of central coordination within the system.

6.6. Application

In the Triple Helix of University-Industry-Government relationships, one could figure out three bilateral relations illustrating a composed information source as dealt with above; they are University-industry, University-Government and Industry-Government relationships. Appendix 4 shows step by step how to compute sectorial, bi-dimensional and three-dimensional entropies, transmission, efficiency, unused capacity and transmission power in a theoretical case. We apply the indicators proposed above to data taken from Leydesdorff (2003), Khan and Park (2011) and those we collected from Web of Science relating to West Africa. For the purpose of this case study, we retained University and industry (UI) bilateral relations and the trilateral (UIG) relations only, i.e. excluding items that have no relations with University, Industry or Government. Therefore, we used $M = 2^2 - 1 = 3$ for the two-dimensional system and $M = 2^3 - 1 = 7$ for the three-dimensional one.

In the example below, U, I, G represent the sectorial output of University only, Industry only and Government only respectively; it means the joint output of two or more sectors are excluded; UI, UG, IG and UIG are the joint output of two or more sectors. In Table 6-2 and Table 6-3, only U, I, G, UI, UG, IG and UIG data were taken from the sources indicated above. Particularly, the two dimensional data (U, I and UI in Table 6-2) are derived from original data in Table 6-3 following data correction process indicated in the two-dimensional case in Appendix 4.

Table 6-2 shows that the overlay between U and I operates largely in South Korea (T_{UI} = 553.796 millibits). This country has the most efficient University-Industry system with $\eta = 0.380$; it is followed by the USA ($\eta = 0.319$) and UK ($\eta = 0.273$). West Africa is at the rear ($\eta = 0.034$), following China ($\eta = 0.126$), Brazil ($\eta = 0.153$) and Russia ($\eta = 0.169$). Even though West Africa has the least efficient system, it occupies the second place after South Korea with respect to the transmission power ($\tau = 0.704$); it means that the region of West Africa devoted 70% of its information capacity production to cooperation or information flow between involved actors. Regarding the transmission power, UK is at the rear, with an efficiency equal to 34.9%.

If the South Korean University-Industry system seems to be the most efficient; it is however less independent because it has the highest transmission power ($\tau = 0.919$); the second least independent system is the West African. The most independent is the UK's system ($\tau = 0.349$), followed by the Brazilian ($\tau = 0.355$). Globally, the West

African University-Industry system is too weak: entropy negligible, efficiency near to 0 and unused capacity closer to 1. From a statistical point of view, this means that the "message" the West African system S = (U, I) produces doesn't contain more information, because entropy measures uncertainty and uncertainty contains information (Shannon, 1948). The situation may be explained by the weakness of the research output of the industrial sector. Indeed, data revealed that in the region, U produces much and I less; as a result, the proportion of the industrial sector output reported to that of the University is marginal. Therefore, it is certain that I won't publish much and unlikely U will enough. As a consequence, the uncertainty in the system is largely reduced, the generated entropy is weak and the unused capacity increases.

The University-Industry-Government system data (Table 6-3) exhibits synergy among the three actors; indeed, the transmission is negative for all countries. However, the synergy operates more in South Korea (T_{UIG} = − 253.382 millibits) than elsewhere; India and USA come far behind with T_{UIG} = − 78.106 millibits and T_{UIG} = − 74.417 millibits respectively. China is at the rear with T_{UIG} =− 14.934 millibits, following West Africa (T_{UIG} =− 16.631 millibits), Brazil (T_{UIG} = − 22.438 millibits) and Russia (T_{UIG} = − 24.206 millibits). The most efficient UIG system is the French one (η = 0.668). Regarding the transmission power, USA devoted the largest part of its information capacity production to the synergy between the Triple Helix spheres; indeed, its transmission power is the highest ($\tau = \tau_1$= 0.299). It is followed by South Korea ($\tau = \tau_1$= 0.286), UK ($\tau = \tau_1$=0.211), Germany ($\tau = \tau_1$ = 0.186) and France ($\tau = \tau_1$ = 0.184). West Africa and China have the lowest transmission power values ($\tau = \tau_1$ = 0.026 and $\tau = \tau_1$= 0.054 respectively).

The West African UIG system exhibits a null synergy or a null information flow between innovation actors; China's system oscillates between null and weak information flow; all the other countries or group of countries (EU, UK, Germany, France, Russia, India, and Brazil) have a weak University-Industry-Government system with respect to the transmission power. Only USA and South Korea show a moderate information flow between innovation actors. Except South Korea that positions among Western countries, the transmission power seems to operate a division of the selected countries into two parts: the developed countries led by the USA, on the one hand, and the developing ones led by India, on the other hand. This ranking of South Korea may be due to the source of data which is the Internet whereas the other countries' data were retrieved from Web of Science databases. Even though India has a transmission higher than that of USA, the transmission power of the USA's system is higher.

Table 6-2. Efficiency (η), unused capacity (ρ) and transmission power (τ) in selected countries or regions' UI system

	U	I	UI	Total	$H_S = H_{UI}$	T_{UI}	η	ρ	τ
USA	192,949	10,954	7,200	211,103	506.286	211.045	0.319	0.681	0.417
EU	202,292	6,737	4,455	213,484	347.454	151.301	0.219	0.781	0.435
UK	53,104	2,251	1,719	57,074	432.93	171.064	0.273	0.727	0.349
Germany	50,255	1,771	1,028	53,054	348.041	161.031	0.220	0.780	0.463
France	25,694	1,489	439	27,622	419.198	248.741	0.264	0.736	0.594
Russia	11,431	402	76	11,909	268.286	187.528	0.169	0.831	0.701
India	6,002	310	97	6,409	391.513	229.118	0.247	0.753	0.584
Brazil	7,831	130	137	8,098	242.034	85.712	0.153	0.847	0.355
China	17,959	243	237	18,439	200.112	75.167	0.126	0.874	0.375
South Korea	2,220	14,023	48	16,291	602.781	553.796	0.380	0.620	0.919
West Africa	883	4	1	888	54.24	37.529	0.034	0.966	0.704

Note: HS and HUI are expressed in millibits

Table 6-3. Efficiency (η), unused capacity (ρ) and transmission power (τ) in selected countries or regions' UIG system.

Country	U	I	G	UI	UG	IG	UIG	Total	$H_S = H_{UIG}$	T_{UIG}	η	$R = H_{max} - H_S$	ρ	$\tau = \tau_1$
USA	152,449	6,506	24,134	7,200	37,834	1,782	2,666	232,571	1,592.102	-74.417	0.567	1.215	0.433	0.299
EU	148,152	3,224	45,920	4,455	52,112	1,485	2,028	257,376	1,647.284	-50.123	0.587	1.160	0.413	0.171
UK	39,316	1,167	12,020	1,719	13,098	394	690	68,404	1,700.159	-63.118	0.606	1.107	0.394	0.211
Germany	35,588	700	8,627	1,028	14,003	407	664	61,017	1,632.406	-43.37	0.581	1.175	0.419	0.186
France	13,571	507	14,020	439	11,593	452	530	41,112	1,872.722	-52.123	0.668	0.931	0.332	0.184
Russia	4,978	102	10,996	76	6,315	162	138	22,767	1,657.682	-24.206	0.591	1.149	0.409	0.093
India	4,134	194	4,563	97	1,813	61	55	10,917	1,730.825	-78.106	0.619	1.070	0.381	0.169
Brazil	6,052	46	1,074	137	1,727	32	52	9,120	1,411.231	-22.438	0.503	1.396	0.497	0.099
China	13,235	61	3,791	237	4,610	68	114	22,116	1,509.404	-14.934	0.538	1.298	0.462	0.054
South Korea	2,210	13,836	4,712	47	10	187	1	21,003	1,308.523	-253.382	0.466	1.499	0.534	0.286
West Africa	780	3	447	1	103	1	0	1,335	1,302.003	-16.631	0.464	1.505	0.536	0.026

Note: H_S and H_{UI} are expressed in millibits

6.7. Indicators at the bounds to the transmission in a two-dimensional system

In a two dimensional system, the transmission's lower and upper limits are 0 and H_{XY}, so that

$$0 \leq T_{XY} \leq H_{XY} \quad (6\text{-}23)$$

6.7.1. Transmission is null ($T_{XY} = 0$)

The transmission is null if and only if the two variables are independent (Cover & Thomas, 2006; Yeung, 2001, p. 24, 2008). The first example considers two independent and identically distributed variables. Thus, the four events 'Neither X nor Y produce' (X = 0, Y = 0), 'X doesn't produce but Y does' (X = 0, Y = 1), 'X produces but Y doesn't' (X = 1, Y = 0) and 'Both X and Y produce' (X = 1, Y = 1) have the same probability, so that the four atoms generated by the subsets engendered by the random variables have (approximately) the same cardinality. Concretely, it means that in a two-dimensional system S = (U, I), the events 'U only produces' (U), 'I only produces' (I), 'U and I produce jointly' (UI) and 'Neither U nor I produce' (O) have (approximately) the same number of items (e.g. $p \cong \frac{1}{4}$). Because the alphabet of the source counts four elements (U, I, UI and O), the maximum value of the entropy is $H_{max} = \log_2 4 = 2$. Therefore, the events are identically distributed, thus, $H_S = H_{UI} = H_{max}$. Then follow:

$$\mathrm{p}(\mathrm{U}=1)=\mathrm{p}(\mathrm{I}=1)=\mathrm{p}(\mathrm{U}=0)=\mathrm{p}(\mathrm{I}=0)=\frac{1}{2}$$

$$\mathrm{H_U}=\mathrm{H_I}=-\frac{1}{2}\log_2\frac{1}{2}-\frac{1}{2}\log_2\frac{1}{2}=-\log_2\frac{1}{2}=\log_2 2=1$$

$$\mathrm{H_{UI}}=4\times\left(-\frac{1}{4}\log_2\frac{1}{4}\right)=\log_2 4=2$$

We can check that

$\mathrm{H_{UI}}=\mathrm{H_U}+H_\mathrm{I}=1+1=2$ and $\mathrm{T_{UI}}=\mathrm{H_U}+H_\mathrm{I}-H_{UI}=1+1-2=0$

The second example relates to the University-Industry system on the one hand and the Industry-Government one on the other hand drawn from the trilateral University-Industry-Government relationship in six[58] West African Member States (Mêgnigbêto, 2014b, 2014c). In these systems 'other'[59] produced, University or Government

[58] They are: Benin, Gambia, Guinea-Bissau, Liberia, Mali and Niger.

[59] 'Other' is used by Loet Leydesdorff in a program he coded for mutual information computation (http://www.leydesdorff.net/th2/th4.exe) to designate items not related to university, industry and government.

produced, but Industry didn't; there isn't any joint output (UI = IG = 0); so that $H_I = 0$, $H_{UI} = H_U$, $H_{IG} = H_G$, and $T_{UI} = T_{IG} = 0$. The variables are independent; $H_{max} = \log_2 4 = 2$ bits, transmission power equals zero, relative unused capacity and efficiency vary according to sectorial outputs.

6.7.2. Transmission equals system's entropy ($T_{XY} = H_{XY}$)

The transmission reaches the system's entropy H_{XY} means that $T_{XY} = H_{XY}$.

Adding $T_{XY} - T_{XY}$ to the right term of Equation (6-3) leads to

$$H_{XY} = H_X + H_Y - T_{XY} + T_{XY} - T_{XY} \tag{6-24}$$

and

$$H_{XY} = (H_X - T_{XY}) + (H_Y - T_{XY}) + T_{XY} \tag{6-25}$$

Because $H_{XY} = T_{XY}$, we can write

$$(H_X - T_{XY}) + (H_Y - T_{XY}) + T_{XY} = T_{XY} \tag{6-26}$$

which is equivalent to

$$(H_X - T_{XY}) + (H_Y - T_{XY}) = 0 \tag{6-27}$$

But $(H_X - T_{XY}) = H_{X|Y}$ and $(H_Y - T_{XY}) = H_{Y|X}$. Besides, $H_{X|Y}$ and $H_{Y|X}$ are all positive or null; therefore, their sum is null if and only if each of them. Thus,

$$\begin{cases} H_{X|Y} = H_X - T_{XY} = 0 \\ H_{Y|X} = H_Y - T_{XY} = 0 \end{cases} \tag{6-28}$$

System of equations (6-28) admits 7 solutions (cf. Appendix 5): i) there is no output in the system (Table 13-10, #1), ii) only one event occurs among the four possible, (Table 13-10, #2-5), iii) each of the variables produce separately only (Table 13-10, #6), iv) other produces and the two variables produces jointly (Table 13-10, #7). This case also is illustrated by six West Africa States' University-Industry or Industry-Government systems data (Mêgnigbêto, 2014b, 2014c); The South Korea University-Industry system in 1999 (Khan & Park, 2011) is a second illustration.[60] Then, marginal entropies, system's entropy and transmission are all equal, transmission power is 1 but efficiency and unused capacity vary depending on variables' value.

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[60] U = 21, I = 23, O = 0 and UI = 0. $H_{UI} = H_U = H_I = T_{UI} = 0.999$ bits, transmission power = 1 and relative unused capacity = 0.501 (M = 4) or 0.632 (M = 3).

6.8. Indicators at the bounds to the transmission in a tri-dimensional system

A three-dimensional transmission has $H_{XYZ} - H_X - H_Y - H_Z$ as lower bound and H_{XYZ} as upper one. The lower bound is negative and the upper one positive; that reflects the possible negativity of the transmission. The resulting inequality $H_{XYZ} - H_X - H_Y - H_Z \leq T_{XYZ} \leq H_{XYZ}$ can be split into two others taking into account the transmission's sign. They are: $H_{XYZ} - H_X - H_Y - H_Z \leq T_{XYZ} \leq 0$ and $0 \leq T_{XYZ} \leq H_{XYZ}$. Therefore, we distinguish three cases below: i) $T_{XYZ} = - H_X - H_Y - H_Z$, ii) $T_{XYZ} = H_{XYZ}$ and iii) $T_{XYZ} = 0$.

6.8.1. Transmission equals system's entropy minus sum of sectorial entropies ($T_{XYZ} = H_{XYZ} - H_X - H_Y - H_Z$)

Equation (6-5) gives:

$H_{XYZ} = H_X + H_Y + H_Z - T_{XY} - T_{XZ} - T_{YZ} + T_{XYZ}$. Thus,

$$H_{XYZ} - H_X - H_Y - H_Z = -T_{XY} - T_{XZ} - T_{YZ} + T_{XYZ} \qquad (6\text{-}29)$$

The left term of Equation (6-29) is the lower bound to T_{XYZ}

If T_{XYZ} takes this value, then we can write:

$$T_{XYZ} = -T_{XY} - T_{XZ} - T_{YZ} + T_{XYZ} \qquad (6\text{-}30)$$

Thus,

$$-T_{XY} - T_{XZ} - T_{YZ} = 0 \qquad (6\text{-}31)$$

Knowing that the bilateral transmissions are null or greater than 0, it comes that $-T_{XY} - T_{XZ} - T_{YZ} = 0$ if and only if bilateral transmissions T_{XY}, T_{XZ} and T_{YZ} are all null, e.g. the random variables X, Y, Z are pairwise independent. Figure 6-3 gives an illustration.

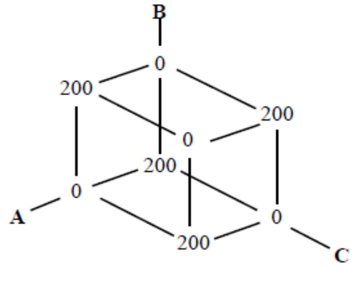

Figure 6-3 Example of variables distribution where the mutual information equals the system's entropy minus the sum of sectorial entropies.

Source: Figure 5 from Krippendorff (2009b, p. 195)

Note : The data source distinguishes three variables named A, B and C. A = 0, B = 0, C = 0, AB = 400, AC = 400, BC = 0, ABC = 200 and O = 400

Let us consider a University-Industry-Government relationships system where individual actors' outputs are null (U = I = G = 0), the joint output UIG also is null (UIG = 0) but bilateral outputs and 'other' have (likely) the same value (UI = UG = IG = O = α, α > 0). Let us consider the bilateral system S = (U, I) drawn from this three-dimensional one. We need first to compute the right output of U, I and UI in the two dimensional system following the method given by Mêgnigbêto (2014a, 2014c).

$U_2 = U_3 + UG_3 = 0 + \alpha = \alpha$;

$I_2 = I_3 + IG_3 = 0 + \alpha = \alpha$;

$UI_2 = UI_3 + UIG_3 = \alpha + 0 = \alpha$;

$O = \alpha$.

Hence, in the two-dimensional system S = (U, I), the outputs are U = I = UI = O = α (α > 0), which refers to a two dimensional system case studied above where $T_{XY} = 0$ and the four events involved are independent and identically distributed. In conclusion, in each two dimensional system derived from the tri-dimensional one, the transmission is null, the system's entropy reaches its maximum value (2 bits), and marginal entropies are each equal to 1 bit. Therefore, in the tri-dimensional system, marginal entropies are equal to 1 bit, bilateral entropies are equal to 2 bits, bilateral transmissions are null. The considered system is composed with 4 events (UI, UG, IG and O) that produce each the same number of units. Therefore,

$$\mathrm{H}_{\mathrm{UIG}} = \sum_1^4 \left(-\frac{1}{4} \times \log_2 \frac{1}{4}\right) = -4 \times \frac{1}{4} \times \log_2 \frac{1}{4} = \log_2 4 = 2 \text{ bits}$$

By applying the formula in Equation (6-6), we get T_{UIG} = - 1 bit. Data are summarized in Table 6-4.

Table 6-4. Indicators of a tri-dimensional system where T_{UIG} reaches its lower bound

Indicator	Value	Indicator	Value
Events UI, UG, IG, O	α > 0	Bilateral transmissions	0 bit
Events U, I, G	0	Transmission (T_{UIG})	-1 bit
H_{UIG}	2 bits	Efficiency (η)	0.667
Marginal entropies	1 bit	Relative unused capacity (υ)	0.333
Bilateral entropies	2 bits	Transmission power $\tau = \tau_1$	1
Observation	System entropy and transmission, bilateral entropies and transmissions, marginal entropies and transmission, efficiency, relative unused capacity and transmission power are invariant whatever α > 0 is.		

6.8.2. Transmission equals system's entropy ($T_{XYZ} = H_{XYZ}$)

Let us consider Equation (6-5):

$$\mathrm{H_{XYZ} = H_X + H_Y + H_Z - T_{XY} - T_{XZ} - T_{YZ} + T_{XYZ}}$$

If $T_{XYZ} = H_{XYZ}$ then it comes that

$$\mathrm{H_{XYZ} = H_X + H_Y + H_Z - T_{XY} - T_{XZ} - T_{YZ} + H_{XYZ}} \qquad (6\text{-}32)$$

That is $\mathrm{H_X + H_Y + H_Z - T_{XY} - T_{XZ} - T_{YZ} = 0}$ (6-33)

and

$$\mathrm{(H_X - T_{XY}) + (H_Y - T_{YZ}) + (H_Z - T_{XZ}) = 0} \qquad (6\text{-}34).$$

Similarly, we can write from Equation (19)

$$\mathrm{(H_X - T_{XZ}) + (H_Y - T_{XY}) + (H_Z - T_{YZ}) = 0} \qquad (6\text{-}35)$$

With a logical reasoning analogous to that in 2 dimensions above, we get

$$\begin{cases} \mathrm{H_{X|Y} = H_X - T_{XY} = 0} \\ \mathrm{H_{Y|Z} = H_Y - T_{YZ} = 0} \\ \mathrm{H_{Z|X} = H_Z = T_{XZ} = 0} \end{cases} \qquad (6\text{-}36)$$

or

$$\begin{cases} \mathrm{H_{X|Z} = H_X - T_{XZ} = 0} \\ \mathrm{H_{Y|X} = H_Y - T_{XY} = 0} \\ \mathrm{H_{Z|Y} = H_Z - T_{YZ} = 0} \end{cases} \qquad (6\text{-}37)$$

The systems of Equations (6-36) and (6-37) are equivalent (Appendix 6).

The system of Equation (6-36) leads to

$$\begin{cases} \mathrm{H_X = T_{XY}} \\ \mathrm{H_Y = T_{YZ}} \\ \mathrm{H_Z = T_{XZ}} \end{cases} \qquad (6\text{-}38)$$

The System of Equations (6–38) admits 12 solutions (Appendix 7): i) there is no output in the system (Table 13-11, #1), ii) only one event occurs (Table 13-11, #2-9), iii) one variable produce and the other two produce jointly only (Table 13-11, #10-12). In the cases where all events' cardinality is null if only one event occurs, the system entropy and transmission, marginal entropies, bilateral entropies, bilateral transmissions are all null; consequently, efficiency is null, unused capacity equals 1 and transmission power is null, by definition. In the case where one sectors produces and the two other sector produce jointly, the system's entropy, the system's transmission, marginal entropies, bilateral entropies, bilateral transmissions are all equal; consequently, transmission power is one. However, unused capacity and efficiency vary according to the variables. Figure 6-4 is an illustration.

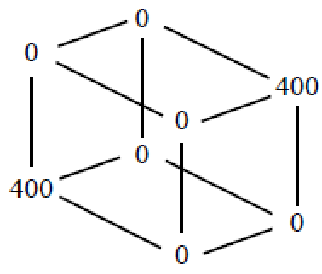

Figure 6-4 Example of variables distribution where the mutual information equals the system's entropy.
Source: Figure 7 from Krippendorff (2009b, p. 195)

Note : The data source' variables and combinations values are A = 400, B = 0, C = 0, AB = 0, AC = 0, BC = 400, ABC = 0 and O = 400

6.8.3. *The transmission is null ($T_{XYZ} = 0$)*

If the transmission is null, the three variables are mutually independent. The first illustration is the theoretical case where the three variables are independent and identically distributed. Therefore, the eight atoms of the universal set have the same cardinality so that corresponding events have the same probability. Concretely, it means that in a three dimensional system S = (U, I, G), the events U, I, G, UI, UG, IG, UIG and O produce the same or approximately the same number of items (e.g. $p \cong \frac{1}{8}$). Therefore, the maximum value of the entropy is $H_{max} = H_{UIG} = \log_2 8 = 3$ bits.

$$\mathrm{H_U} = \mathrm{H_I} = H_G = -\frac{1}{2}\log_2\frac{1}{2} - \frac{1}{2}\log_2\frac{1}{2} = 1 \text{ bit}$$

$$\mathrm{H_{UI}} = \mathrm{H_{UG}} = \mathrm{H_{IG}} = 4 \times \left(-\frac{1}{4}\log_2\frac{1}{4}\right) = 2 \times \log_2 2 = 2 \text{ bits}$$

Bilateral transmission are null; for example $T_{UI} = H_U + H_I - H_{UI} = 1 + 1 - 2 = 0$. Consequently, $H_{UIG} = H_U + H_I + H_G = 3$ bits. Therefore, efficiency equal 1, relative unused capacity is null; as transmission is null, transmission power as well.

The second illustration consists of examples from the West African States cases (Table 6-5). Six of them have a null industrial output, so UI, IG and UIG are null. T_{UIG} is null, but not all bilateral transmissions. Figure 6-5 illustrates this case as well. These results contrast with the consequence of variables independency theorem stating that when at a system's level the transmission is null, variables are mutually independent and also pairwise independent (Yeung, 2001, pp. 125–127, 2008). Accordingly, we should have bilateral transmissions equal 0; that is not the case. According to Leydesdorff (2014), this happens because the mutual information in three or more dimensions is not a Shannon-type information. Krippendorff (2014) claims that this is a proof that algebra is not able to get unique interactions among three or more variables for the simple reason that probabilities do not take care of circular interactions which begin with three or more variables (Krippendorff, 2009a, 2009b).

Table 6-5. University, industry and government's scientific production (numbers of papers) and relations in six West African countries (2001-2010)

Country	Total	U	I	G	UI	UG	IG	UIG
Benin	1,335	548	0	668	0	93	0	0
Gambia	986	7	0	208	0	5	0	0
Guinea	241	49	3	168	0	11	0	0
Guinea Bissau	225	16	0	185	0	13	0	0
Liberia	49	14	0	26	0	4	0	0
Mali	1,204	517	0	569	0	85	0	0
Niger	586	196	0	304	0	16	0	0

Source: Mêgnigbêto (2014b, 2014c)

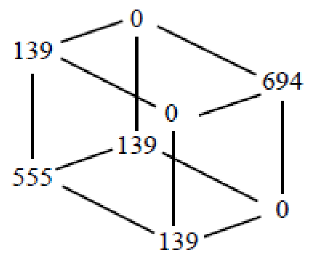

Figure 6-5 Example of variables distribution where the mutual information is null.
Source: Figure 6 from Krippendorff (2009b, p. 194)

Note : The data source variables and their combinations values are A = 555, B = 0, C = 0, AB = 139, AC = 139, BC = 694, ABC = 139 and O = 0

6.9. Indicators in other special cases

6.9.1. Two-dimensional system S = (U, I): U = I = UI = α > 0, O is not included

The total output is 3α. Therefore,

$$\mathrm{p(U = 1, I = 0) = p(U = 0, I = 1) = p(U = 1, I = 1)} = \frac{1}{3}$$

and

$$\mathrm{H_{UI}} = 3 \times \left(-\frac{1}{3}\log_2\frac{1}{3}\right) = \log_2 3 = 1.585 \text{ bits}$$

$$\mathrm{p(U = 1) = p(I = 1)} = \frac{1}{3}$$

and

$$\mathrm{p(I = 0) = p(I = 0)} = \frac{2}{3}$$

$$\mathrm{H_U} = \mathrm{H_I} = -\frac{1}{3}\log_2\frac{1}{3} - \frac{2}{3}\log_2\frac{2}{3} = 0.918 \text{ bits}$$

and

$$\mathrm{T_{UI} = H_U + H_I - H_{UI}} = 0.252 \text{ bits}$$

Because O is excluded, M = 2^n - 1 = 3 and H_{max} = $\log_2 3$ = H_{UI}, so transmission power equals 1. In this case, marginal entropies, joint entropy, transmission, efficiency, unused capacity and transmission power are invariant whatever α positive (Table 6-6).

Table 6-6. Indicators of a bi-dimensional system where U = I + UI = α > 0 (O not considered)

Variable	Output	Probability	Entropy (bits)	Indicators	
U only	α	0.333	H_U = 0.918	Transmission (T_{XY})	0.252
I only	α	0.333	H_I = 0.918	Efficiency (η)	1
UI	α	0.333	H_{UI} = 1.585	Relative unused capacity (υ)	0
Total	3α			Transmission power (τ)	0.159
Observation	System entropy and transmission, bilateral entropies and transmissions, marginal entropies and transmission, efficiency, relative unused capacity and transmission power are invariant whatever α > 0 is.				

6.9.2. Three-dimensional system S = (U, I, G): all events have the same probability, O not included

By considering separately each of the three bilateral systems derived from the trilateral one, S = (U, I), S = (I, G) or S = (U, G) and by proceeding to data correction like in Mêgnigbêto (2014a, p. 291) or Mêgnigbêto (2014c), we found that marginal entropies are all equal, bilateral entropies the same and bilateral transmissions. Their values are invariant (Table 6-7).

Table 6-7. Indicators of a tri-dimensional system where events are identically distributed (O not included)

Indicator	Value	Indicator	Value
Events cardinality	$\alpha > 0$	Relative unused capacity (υ)	0.167
H_{UIG}	2.807 bits	Transmission (T_{UIG})	- 0.088 bits
Marginal entropies	0.985 bits	Efficiency (η)	1
Bilateral entropies	1.950 bits	Relative unused capacity (υ)	0
Bilateral transmissions	0.020 bits	Transmission power $\tau = \tau_1$	0.591
Observation:	System entropy and transmission, bilateral entropies and transmissions, marginal entropies and transmission, efficiency, relative unused capacity and transmission power are invariant whatever $\alpha > 0$ is.		

6.9.3. Three-dimensional system S = (U, I, G): all events have the same probability, O not included, UIG = 0

By considering separately each of the three bilateral systems derived from the trilateral one S = (U, I), S = (I, G) or S=(U, G) and by proceeding to data correction like in Mêgnigbêto (2014a, p. 291) and Mêgnigbêto (2014c), we compute indicators for such a system (Table 6-8).

Table 6-8. Indicators of a tri-dimensional system where events are identically distributed (O not included and IUG = 0)

Indicator	Value	Indicator	Value
Events (except UIG)	$\alpha > 0$	Relative unused capacity (υ)	0.079
H_{UIG}	2.585 bits	Transmission (T_{UIG})	- 0.170 bits
Marginal entropies	1 bit	Efficiency (η)	0.921
Bilateral entropies	1.918 bits	Relative unused capacity (υ)	0.079
Bilateral transmissions	0.082 bits	Transmission power $\tau = \tau_{1\,=}$	0.409
Observation	System entropy and transmission, bilateral entropies and transmissions, marginal entropies and transmission, efficiency, relative unused capacity and transmission power are invariant whatever $\alpha > 0$ is.		

6.10. Discussion and conclusion

In the scientific literature, the quantity we defined as unused capacity is called redundancy and the relative unused capacity called relative redundancy (Cover & Thomas, 2006; Mori, 2006; Yeung, 2001, 2008). Leydesdorff (2010a) and Leydesdorff and Ivanova (2014) defined redundancy as the fraction of the capacity that is not used; besides, they recognized that this definition may seem counterintuitive because redundancy is intuitively associated with the overlapping information. In our opinion, the system has the capacity to produce information up to H_{max}, but really produces H_S. Therefore, $H_{max} – H_S$ is unproduced. It may be called redundancy only if it were really produced but didn't serve in communication. Besides, Leydesdorff and Ivanova (2014) assumed that the redundancy $R = H_{max} – H_S$ equals the transmission in absolute size; they also demonstrated that when the number of dimensions is even, redundancy and transmission have opposite signs and have both the same sign otherwise. That is $R_{XY} = – T_{XY}$ (in case of a two dimensional system) and $R_{XYZ} = T_{XYZ}$ in a three-dimensional system. If R is negative in a two-dimensional system, it comes out that H_{max} is lower than H_S, which is mathematically absurd. Furthermore, according to our computation (Table 6-9), the two quantities R and T_{UI} or T_{UIG} do not exhibit any equality.

Table 6-9. Comparison of the redundancy (R) with the system entropy (data are in millibits of information)

	Two-dimensions			Three-dimensions		
	H_{UI}	$R = H_{max} - H_{UI}$	T_{UI}	H_{UIG}	$R = H_{max} - H_{UIG}$	T_{UIG}
USA	506.286	1,078.68	211.045	1,592.102	1,215.25	-74.417
EU	347.454	1,237.51	151.301	1,647.284	1,160.07	-50.123
UK	432.93	1,152.03	171.064	1,700.159	1,107.20	-63.118
Germany	348.041	1,236.92	161.031	1,632.406	1,174.95	-43.37
France	419.198	1,165.76	248.741	1,872.722	934.63	-52.123
Russia	268.286	1,316.68	187.528	1,657.682	1,149.67	-24.206
India	391.513	1,193.45	229.118	1,730.825	1,076.53	-78.106
Brazil	242.034	1,342.93	85.712	1,411.231	1,396.12	-22.438
China	200.112	1,384.85	75.167	1,509.404	1,297.95	-14.934
South Korea	602.781	982.18	553.796	1,308.523	1,498.83	-253.382
West Africa	54.24	1,530.72	37.529	1,302.003	1,505.35	-16.631

In this chapter, we showed that any information source composed with n random variables of which each has the alphabet {0,1} may be split into $M = 2^n$ events. We computed the maximum entropy of the system and derived indicators like the efficiency, the unused capacity and the transmission power of the system. We defined the efficiency of a system as the fraction of its information production capacity that is really produced. The relative unused capacity is the fraction of the capacity of the system that is not used for information production. The transmission power measures the efficiency of the mutual information; it indicates how strong the information flow or the control exerted within the system is. Particularly, in case where the relations are reduced to the Triple Helix actors' output only, the n-tuple $\{0\}^n$ is excluded leading to $M = 2^n – 1$. We computed these indicators for data taken from the scientific literature or directly from the Web of Science's databases and related to different countries or regions. With such indicators, a same system may be compared over time; different systems may also be compared.

We also found out two- and three-dimensional configurations where mutual information reaches its bounds and computed efficiency, unused capacity and transmission power for such systems as well as for some particular cases.

The two-dimensional transmission reaches its upper bound, if there is no output within the system, only one actor produces (other included), or if other produces and the two actors produce jointly. The three-dimensional transmission takes its maximum value if there is no output within the system, or if only one actor produce (other included) or if one actor produces and the other two actors produced jointly. Mutual information in a two-dimensional system is null if the two variables are independent; in a three dimensional system, the mutual information is null is the three variables are mutually independent; however, this doesn't meant that the variables are pairwise independent. In a three dimensional system, mutual information reaches its lower bound if variables are pairwise independent. For these cases, transmission power is either null or 1, entropies, unused capacity or efficiency vary according to the system configuration.

In a two-dimensional system where other is not considered and the two actors produce separately equally as they produce jointly, the system's entropy is invariant, bilateral entropies are invariant and equal, transmission power equal 0.159. In a three-dimensional system where all events have the same probability and other not considered, entropies and transmission are invariant, transmission power equals τ_1 = 0.591. In a three-dimensional system where all events have the same probability, the joint output of the three actors is null and other not considered, entropies and transmission are invariant, and transmission power equals $\tau_1 = 1$.

Efficiency, relative unused capacity and transmission power ranges from 0 to 1. Their interpretation may be inspired from practices in association coefficients: they may be said null or negligible if their value is lower or equal to 0.05 (or 5%); if their value is over 0.05 and less than 0.25 (25%), they are weak; they are moderate if their value is between 0.25 and 0.60 (25% and 60%); over 0.6 (e. g 60%), they may be said strong.

The reflections above may be extended to four or more dimensions; for example, one may consider internationally co-authored documents as Leydesdorff and Sun (2009) did, or also distinguish these types of collaboration into 'foreign University', 'foreign Industry' or 'foreign Government' and assess international Triple Helix actors influence on a country or region's economic performance. These reflections may also apply to any field of collaboration between University, Industry and Government, and not only to research output, for example funding, grants, etc.

We also made the equivalence between "events have the same probability" and the "associated sets have the same cardinality". In fact, the associated set to events may have likely the same cardinality; the result is approximately identic. For example, in case of a two dimensional system, if the four cardinalities are 100, 98, 96, and 94 yields the same indicators as all four cardinalities are equal to 100.

7. Information flow within the West African innovation systems

We use the mutual information and the transmission power as indicators of knowledge circulation between innovation actors. The unit of analysis is scientific publications indexed in Web of Science with at least one West African-based address. We find that at the regional level, University is the biggest knowledge producer followed by Government and Industry in that order; however, at the national level, Government is the biggest information producer in the majority of countries. Industrial sector output is weak both at the regional level and individual countries level. It is even null in some countries. The mutual information indicated the existence of synergy between the three actors, both at the regional and the national level. However, its value is too low to allow knowledge circulating fluently among actors.

The text is based on a brief communication published in ISSI Newsletter (Mêgnigbêto, 2014b) and an article published in the Triple Helix Journal (Mêgnigbêto, 2014c).

7.1. Introduction

The role of University, Industry and Government has been changing for recent decades; university does not only teach and do research but can compete with firms as well, for example as far as call for tends, bids or services are concerned; Government does not only set up rules, watch over their respect, fund and collect taxes but can also institute administrative body to do research or participate to firms capital; Industry does not only output services, processes and products for the community but can conduct research for their improvement. Each sector is taking the role of another. Etzkowitz and Leydesdorff elaborated, on this basis, the Triple Helix concept that represents the necessary dynamics among the three sectors (cf. Etzkowitz & Leydesdorff, 1995, 2000; Leydesdorff & Etzkowitz, 2001). If research activities exploit existing knowledge and produce new ones, knowledge circulation between University and Industry ensures its transformation into innovation. Innovation takes an important place in industrial development, economic growth and wealth production. There is a positive correlation between the levels of research and development activities, the level of absorptive capacity and the pool of knowledge that can be exploited (Mueller, 2006, p. 1500). Hence, knowledge flow between actors can indicate a society's level of development and the self-organization.

The Oslo Manual (OECD & EUROSTAT, 2005, p. 46) defines innovation as «the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations». In other words, innovation supposes new things, new ways of doing, creativity, added value. In the Triple Helix model, innovation results from interactions between three main actors: University, Industry and Government (Etzkowitz & Leydesdorff, 1995, 2000). Research and innovation can be measured; collaboration for research and innovation too (OECD, 2010; OECD & EUROSTAT, 2005; Şerbănică, 2011). Leydesdorff (2003) introduces the mutual information as an indicator of the Triple Helix of relations between University Industry and Government, based on the Shannon's (1948) notion of entropy and Mêgnigbêto (2014a) proposed transmission power as the efficiency of the mutual information. The mutual information indicates the synergy or information flow between innovation actors and transmission power the strength of information flow within a system or between its actors. Transmission power may help in measuring the level of synergy, the pressure or the control exerted within the system.

West Africa, one of the five African regions as determined by the African Union,[61] counts 15 countries (listed alphabetically as follows: Benin, Burkina Faso, Cote d'Ivoire, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Nigeria, Niger, Senegal, Sierra Leone and Togo). All the West African countries are together member of the Economic Community of West African States (ECOWAS), a regional economic integration organisation. In early 2012, the region adopted the ECOWAS Policy on Science and Technology (ECOPOST) that recognized the role of science, technology and innovation in regional integration and life conditions improvement. From their independence early 1960s to the end of the Cold War (end of 1980s), African States and hence almost all the ECOWAS Members States were ruled by single-party authoritarian regimes with central control and a state monopoly in all sectors of the economy. The fall of the Berlin Wall in 1989 had changed geopolitical strategies at international level, mainly in Western countries, so most of the developing countries were forced to switch over to democracy with a liberalized political and economic system. West Africa integration institutions and Member States have recognized democracy as a system that sustains peace, stability, economic growth, social and economic development and a condition to regional integration (ECOWAS Commission, 2011b) and committed to "deepen and strengthen the democratic institutions using appropriate international standards" with an "ECOWAS of people" as target.

The Triple Helix of University-Industry-Government relationships ensures the knowledge flow among the three sectors and contributes to economic growth and hence to social and economic development. Through innovation and the renewal of the political economy and social structure, the Triple Helix is the key to knowledge-based economic development (Leydesdorff & Etzkowitz, 2001) because knowledge creation, flows and capitalisation are also important elements in stimulating economic development and contributes to regional growth (Mueller, 2006). The aim of this chapter is to measure knowledge flow between innovation actors in the West African region. Our research question is: how does information circulate among

[61] Resolution CM/Res.464 (XXVI) adopted by the African Unity Organisation (now African Union) Council of Ministers meeting in its twenty sixth ordinary session in Addis-Ababa (Ethiopia) from 23 February to 1st March 1976. The countries list was updated in 2004.

innovation actors in West Africa? For this purpose, we use mutual information and transmission power as indicators.

7.2. Literature review

The exploitation of knowledge requires it to be produced, circulate and be acquired (Mueller, 2006, p. 1500). Şerbănică (2011, p. 46) gave an overview of knowledge circulation indicators; she distinguished funding flow **(**in the form of grants, donations and contracts), cooperation, strategic partnerships, co-publications, and patents statistics. Research collaboration has become an indicator of scientific collaboration (Abbassi et al., 2012; Bordons & Gomez, 2000; Katz & Martin, 1997; Olmeda-Gómez et al., 2008). Co-authorship is often used as measurement of it mainly in academia, and an evidence of tacit transfer of information and knowledge as well. Several publications studied co-authorship worldwide (e.g. Adams, 2012; Adams et al., 2014; Bordons & Gomez, 2000) or in Africa (e.g. Adams et al., 2014; Adams et al., 2010; Boshoff, 2009, 2010; Mêgnigbêto, 2013e; Onyancha & Maluleka, 2011b; Tijssen, 2007; Toivanen & Ponomariov, 2011). They all reported an increasing trend in the number of authors who contributed to an article; some of them underlined the concentration of the growth in the group of papers with 5 or more authors, lending strong importance to collaboration. Globally, co-authorship has exploded recently (Adams, 2012) and internationalisation of collaboration characterizes science today (Adams, 2013).

Number of studies used citations analysis (e.g. Onyancha & Maluleka, 2011b; Ponomariov & Toivanen, 2014; Toivanen & Ponomariov, 2011) or economic data (Mueller, 2006) to measure knowledge transfer; however, they did neither distinguish the three actors University, Industry and Government nor used information theory. Some other studies (Khan & Park, 2011; Leydesdorff, 1991, 2003; Leydesdorff & Sun, 2009; Park & Leydesdorff, 2010; Ye et al., 2013) focused on University, Government and Industry collaboration using information theory, especially mutual information; but, they concentrated on European and Asian countries only. Particularly for Africa, University-Industry-Government relationships were dealt with by Nwagwu (2008) for Nigeria, Taylor (2004) for South Africa, Mêgnigbêto (2013g) for West Africa and Etzkowitz and Dzisah (2007) for the whole Africa; in 2012, the Association of African Universities conducted a survey on University-Industry linkages in Africa in order to determine what interface structures, policies, positions, incentives, and funding avenues are currently in place (or lacking) and what services or interventions African institutions themselves gauge to be most important for strengthening their efforts (Ssebuwufu et al., 2012). The above studies on Africa described and analysed relationships between University, Industry and Government; in addition, Mêgnigbêto (2013g) discussed the information flow between Triple Helix actors in West Africa; but he based his study on mutual information only which is not suitable for comparison; contrary, the transmission power is (Mêgnigbêto, 2014a). So, how does the transmission power measures information circulation within West African innovation systems?

7.3. Data and methods

7.3.1. Data collection

The elaboration of the Triple Helix thesis lays on collaboration between University, Industry, and Government. Of course, collaboration may cover several aspects and not all collaboration yields publications. In this chapter however, we focus on research collaboration understood as co-authorship. We downloaded West African scientific publications data from Thomson Reuters' Web of Science over a ten-year period (2001-2010). The databases selected were Science Citation Index Expanded (SCI-EXPANDED), Conference Proceedings Citation Index-Science (CPCI-S), Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH) and Index Chemicus (IC). The search expression was *cu=benin or cu=cote ivoire or cu=niger or cu=senegal or cu=cape verde or cu=gambia or cu=ghana or cu=nigeria or cu=togo or cu=mali or cu=liberia or cu=sierra leone or cu=guinea or cu=burkina faso or cu=guinea-bissau*. The 28,380 resulting records were downloaded and imported into a bibliographic database managed with the CDS/ISIS[62] software application. Based on Leydesdorff's (2003) method for label assignment to addresses, we coded a CDS/ISIS Pascal[63] programme that assigned each address the label 'University' (abbreviated UNIV, 'Industry' (abbreviated INDU) or 'Government' (abbreviated GOV) to each address. A record may contain many addresses; therefore, one record may have two or more different labels. The CDS/ISIS programme was also instructed to read the countries' name from the addresses and automatically add the associated two characters ISO codes to the label. Non-West African countries were given unique identifiers ZZ. Therefore, in the inverted file, a university in Benin appears under the label UNIV-BJ, an enterprise in a non-West African country appears under INDU-ZZ.

The CDS/ISIS search function operates mainly over the inverted file that contains "searchable terms" as previously defined by the database administrator upon a field. It admits the Boolean operators OR symbolized by the sign + (plus), AND symbolized by the character * (star) and NOT symbolized by the character ^ (circumflex). We run searches over the CDS/ISIS database using key-words composed of each country names and Triple Helix actors' codes. For examples, the searches expressions (1) to (7) were conducted for Benin:

(1) UNIV-BJ: retrieves all records University in Benin authored;
(2) INDU-BJ: retrieves all records Industry in Benin authored;
(3) GOV-BJ: retrieves all records Government in Benin authored;
(4) UNIV-BJ * INDU-BJ retrieves all records University and Industry in Benin co-authored;

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[62] CDS-ISIS is text database management software developed and distributed by UNESCO (1989a).

[63] CDS/ISIS provides a programming language "designed to develop CDS/ISIS applications requiring functions which are not readily available in the standard package" (UNESCO, 1989b). This programming language enables users to extend functions of the standard package, to make it more robust and in order to meet users' specific needs (Mêgnigbêto, 1998).

(5) UNIV-BJ * GOV-BJ retrieves all records University and Industry in Benin co-authored;
(6) INDU-BJ * GOV-BJ retrieves all records Industry and Government in Benin co-authored;
(7) UNIV-BJ * INDU-BJ * GOV-BJ retrieves all records University, Industry and Government in Benin co-authored.

Finally, the contribution of each actor was computed as follows (according to the Venn diagram in Figure 7-1):
U = (1) – (4) – (5) + (7): number of publications University only authored;
I = (2) – (4) – (6) + (7): number of publications Industry only authored;
G = (3) – (5) – (6) + (7): number of publications Government only authored;
UI = (4) – (7): number of publications University and Industry only co-authored;
UG = (5) – (7): number of publications University and Government only co-authored;
IG = (6) – (7): number of publications University and Industry only co-authored;
UIG = (7): number of publications University, Industry and Government co-authored.

Such searches and computation were run for individual countries and then for the whole region.

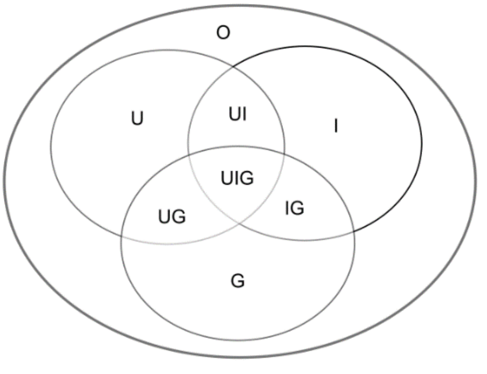

Figure 7-1 Cardinalities in a three dimensional system S = (U, I, G)

7.3.2. Entropy, mutual information, efficiency and transmission power

Shannon (1948, p. 394) defined the entropy of an event that occurs with the probability p as:

$$\mathrm{H} = -\mathrm{p} \times \log_2 \mathrm{p} - (1 - \mathrm{p}) \times \log_2 (1 - \mathrm{p}) \quad (7\text{-}1)$$

where $\log_2$ is the logarithm to the base 2; the entropy may however be computed to other bases e.g.3,4, ..., 10). More generally, if $\mathrm{X} = (\mathrm{x}_1, \mathrm{x}_2, \dots, \mathrm{x}_\mathrm{n})$ is a random variable and its components occur with the probabilities $\mathrm{p}_1, \mathrm{p}_2, \dots, \mathrm{p}_\mathrm{n}$ respectively, then the entropy generated by X is (cf. Shannon, 1948; Shannon & Weaver, 1949, p. 14)

$$\mathrm{H_X} = -\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{p_i} \times \log_2 \mathrm{p_i} \quad (7\text{-}2)$$

An information source is a random variable that produces symbols (Cover & Thomas, 2006; Le Boudec et al., 2013, p. 8; Mori, 2006; Shannon, 1948, p. 392). An information source may also be composed of two or more random variables. For two random variables X and Y (two dimensions), if H_X is the entropy of X and H_Y that of Y, the joint entropy H_{XY} of the two variables is equal to the entropy H_X plus H_Y minus the entropy of the overlay of X and Y. The latter is called "rate of transmission" (Shannon, 1948, p. 407) or mutual information (Cover & Thomas, 2006; Leydesdorff, 2003; Mori, 2006; Yeung, 2001, 2008) between X and Y. The relations between the transmission, T_{XY}, the joint entropy H_{XY} and the marginal entropies of the variables, H_X and H_Y, are (Shannon, 1948, p. 409):

$$\mathrm{H}_{\mathrm{XY}} = \mathrm{H}_{\mathrm{X}} + \mathrm{H}_{\mathrm{Y}} - \mathrm{T}_{\mathrm{XY}} \tag{7-3}$$

and

$$\mathrm{T}_{\mathrm{XY}} = \mathrm{H}_{\mathrm{X}} + \mathrm{H}_{\mathrm{Y}} - \mathrm{H}_{\mathrm{XY}} \tag{7-4}$$

In case of three random variables X, Y and Z (three dimensions), Leydesdorff (2003) [64] demonstrated that the relations between the system's entropy, its transmission, the marginal entropies and the bilateral transmissions are given by

$$\mathrm{H}_{\mathrm{XYZ}} = \mathrm{H}_{\mathrm{X}} + \mathrm{H}_{\mathrm{Y}} + \mathrm{H}_{\mathrm{Z}} - \mathrm{T}_{\mathrm{XY}} - \mathrm{T}_{\mathrm{XZ}} - \mathrm{T}_{\mathrm{YZ}} + \mathrm{T}_{\mathrm{XYZ}} \tag{7-5}$$

and

$$\mathrm{T}_{\mathrm{XYZ}} = \mathrm{H}_{\mathrm{X}} + \mathrm{H}_{\mathrm{Y}} + \mathrm{H}_{\mathrm{Z}} - \mathrm{H}_{\mathrm{XY}} - \mathrm{H}_{\mathrm{YZ}} - \mathrm{H}_{\mathrm{XZ}} + \mathrm{H}_{\mathrm{XYZ}} \tag{7-6}$$

The transmission or the mutual information may be used as innovation indicator. According to Leydesdorff (2003), in more than two dimensions, if the transmission is negative, it indicates the level of synergy or information flow between variables; if it is positive, it indicates how centrally controlled is the system; a null transmission means an absence of interactions between variables. However, Krippendorff (2009a, 2009b) claims that mutual information doesn't measure the unique interactions in a complex system and a null transmission could not be interpreted as absence of interaction within a system.

Mêgnigbêto (2014a) defined the efficiency of a system as the fraction of its information production capacity that is really produced; relative unused capacity is the complement to 1 of the efficiency; the transmission power of a system is the fraction of the maximum value of the transmission devoted to information sharing in the system. It represents the share of the "total configurational information" really produced in the system. In other words, it measures the efficiency of the mutual information. All the three indicators vary from 0 to 1; they all are dimensionless and may be expressed as a percentage.

[64] Citing McGill (1954), Theil (1972) and Abramson (1963).

In a three-dimensional one, two types of transmission power are distinguished (Mêgnigbêto, 2014a, p. 287): the first one (τ_1) when the transmission is negative, and the second (τ_2) when the transmission is positive:

$$\boldsymbol{\tau} = \begin{cases} \tau_1 = \frac{T_{XYZ}}{H_{XYZ} - H_X - H_Y - H_Z} \text{ if} T_{XYZ} < 0 \\ \tau_2 = \frac{T_{XYZ}}{H_{XYZ}} \text{ if} T_{XYZ} > 0 \\ 0 \text{ if} T_{XYZ} = 0 \end{cases} \tag{7-7}$$

7.4. Results

7.4.1. Sectorial outputs and collaboration data

University produced 82.82% of papers, Government 41.09%, and Industry 1.07%. Research institutions that do not fall under the above categories include NGOs, national or international associations; they account for 3.80%. If data are restricted to West African-based institutions, University produces 67.45% of papers, Industry 0.52% and Government 31.69%; not classified institutions' share rises to 11.46%. The breakdown of records with West African-based addresses per year and Triple Helix actor alongside with their combinations are given in Table 7-1. Annual data show the same trend and confirm University (U) as the biggest science producer. Due to the effect of the Boolean operator AND, University and Government (UG) produce jointly more than University and Industry (UI) on the one hand and Industry and Government (IG) on the other hand; the double Boolean operator makes the joint output of the three sector (UIG) smaller; these results confirm the findings of (Khan & Park, 2011). At national levels however (Table 7-2), Government is the biggest information producer, ahead University and Industry in 12 countries; even some countries (Benin, Gambia, Guinea-Bissau, Liberia, Mali and Niger) have no industrial output. Globally, the industrial sector's output is weak both at regional and national level, which indicates that the sector didn't use to do research in West Africa.

7.4.2. Knowledge flow between actors

We used mutual information (Leydesdorff, 2003), efficiency and transmission power (Mêgnigbêto, 2014a) as measurements of knowledge circulation among the Triple Helix actors. The unit of analysis is publications. The regional University-Industry-Government system data are output in Table 7-3. The entropy (H_{UIG}) ranges from 1.207 bits in 2009 to its highest value (1.367 bits) in 2003; no trend is depicted over the period (Figure 7-2). It comes that, from 2001 to 2010, the West African innovation system produced less than half its capacity; indeed, annual efficiencies (η) are lower than one half, ranging from 43% to 48%. Annual transmissions (T_{UIG}) are negative indicating synergy among actors; in other words, the system is not centrally controlled over the studied period of times; however the interactions between actors are too low and cannot ensure better knowledge circulation. Indeed, transmission varies from -13 to -32 millibits; and, as a consequence, transmission power (τ) ranges from 0.026 to 0.057 meaning that 3 to 6% of the system's information sharing capacity was really used. In other words, much information doesn't circulate among innovation actors in West Africa. Synchronous data (Table 7-3, Row Total) reveals that the West African innovations system products 1.301 bits of information representing 46% of its capacity; the synergy is evaluated to – 19 millibits that is 4% of the information sharing capacity.

The comparison of bilateral transmissions (T_{UI}, T_{UG} and T_{IG}) reveals that whatever the year is, the entropy of University-Government system (H_{UG}) is higher than that of University-Industry system (H_{UI}) which in turn is higher than that of Industry-Government system (H_{IG}); the system's entropy (H_{UIG}) is the highest (Figure 7-2).

Entropy measures uncertainty; when the transmission (T_{UIG}) is negative, it contributes to the reduction of the uncertainty that prevails at the system level (Leydesdorff, 2003). In Equation (7-6), the right term groups entropies, thus positive values; however, bilateral entropies are affected with the negative sign; therefore, the higher they are, the more negative the transmission. In other words, bilateral entropies contribute to the reduction of the uncertainty at the system level. In the case of the West African innovation system, $H_{UG} > H_{UI} > H_{IG}$ over 2001-2010 (Figure 7-2); we conclude that at the tri-lateral system level, the University-Government relations contribute more to the uncertainty reduction than the other two bilateral systems.

At national levels, because industrial output is null in some countries, H_{UI} and H_U on the one hand and H_{IG} and H_G on the other hand are equal; therefore, the transmission between the industrial sector and the two others are null as far as these countries are concerned. In the remaining countries, T_{UI} and T_{IG} are weak (0.1 to 10 millibits). Whatever the country is, H_{UG} is greater than H_{UI} and H_{IG}, T_{UG} than T_{UI} and T_{IG}. The national system with the highest entropy is the Sierra Leonean (H_{UIG} = 1.387 bits) and the one with the lowest value is the Gambian (H_{UIG} = 0.359 bits). Cape Verde has the highest transmission (T_{UIG} = - 217 millibits) and the six countries with 0 output for industrial sector has a null transmission. Gambia has however the less efficient system (η = 13%) and Ghana the most efficient one (η = 55%). Out of the nine countries with a non-null transmission, Cap Verde has the highest transmission power ($\tau = \tau_1 = 0.245$) and Burkina Faso the lowest ($\tau = \tau_1 = 0.010$). These data suggest that the amount of knowledge that circulates among actors is larger in Cape Verde than elsewhere in West Africa, and that the Cape-Verdean innovation system share more information among its actors than elsewhere.

7.5. Discussion

Among the 15 West African Member States, six has no industrial output; over the remaining, two (Ghana and Nigeria) exhibit relationships between Industry and Government on the hand and Industry and University on the other hand; but the joint collaboration between the three actors occurs only in Nigeria. These results show that there is no tradition in industrial research in the region. Indeed, the West African industrial sector is facing a number of problems that make less than half its capacity is really used (ECOWAS Commission, 2010a; Mêgnigbêto, 2013g). The numerous untapped underground and mineral resources the region is endowed with are exported rather than processed locally (ECOWAS Commission, 2010a), so final products are mainly conceived out of Africa and not for African. Consequently, local Industry doesn't need research activities to improve products, processes or services.

Table 7-1.West African scientific output (number of publications) per Triple Helix actor.

	U	I	G	UI	UG	IG	UIG	Total
2001	780	3	447	1	103	1	0	1,335
2002	884	6	454	0	129	1	0	1,474
2003	925	8	482	3	156	1	0	1,575
2004	1,011	4	463	2	151	0	0	1,631
2005	1,410	6	657	3	252	1	0	2,329
2006	1,507	6	644	4	238	0	2	2,401
2007	2,086	7	735	7	327	1	0	3,163
2008	2,356	10	747	13	400	4	3	3,533
2009	2,756	7	739	11	427	1	1	3,942
2010	2,684	12	926	12	497	2	2	4,135
Total	16,399	69	6,294	56	2,680	12	8	25,518

Table 7-2. University, Industry and Government's scientific production (numbers of papers) and relations per West African country

Country	Total	U	I	G	UI	UG	IG	UIG
Benin	1,335	548	0	668	0	93	0	0
Burkina Faso	1,785	484	1	1,114	0	164	0	0
Cape Verde	52	14	3	26	0	1	0	0
Cote d'Ivoire	1,669	784	1	808	0	144	0	0
Gambia	986	7	0	208	0	5	0	0
Ghana	3,203	1,821	30	1,371	7	393	5	0
Guinea	241	49	3	168	0	11	0	0
Guinea Bissau	225	16	0	185	0	13	0	0
Liberia	49	14	0	26	0	4	0	0
Mali	1,204	517	0	569	0	85	0	0
Niger	586	196	0	304	0	16	0	0
Nigeria	15,569	13,669	101	2,683	53	1339	14	7
Senegal	2,544	1,062	3	1,172	0	180	0	0
Sierra Leone	117	48	2	60	0	8	0	0
Togo	433	225	1	191	0	26	0	0

Table 7-3. Mutual information, efficiency and transmission power in the West African regional innovation system

Year	H_{UI}	H_{UG}	H_{IG}	T_{UI}	T_{UG}	T_{IG}	H_{UIG}	T_{UIG}	η (%)	τ (%)
2001	955.865	1,286.049	1,012.942	2.442	614.590	0.555	1,302.003	-16.631	46.38	2.62
2002	931.816	1,305.719	1,011.110	8.000	559.293	1.064	1,312.687	-27.457	46.76	4.61
2003	955.245	1,341.708	1,035.819	4.492	527.666	2.930	1,366.786	-32.054	48.69	5.65
2004	897.325	1,281.585	988.034	1.650	537.846	2.513	1,294.369	-18.098	46.11	3.23
2005	899.961	1,321.885	1,003.876	2.292	505.689	1.336	1,339.818	-18.384	47.73	3.48
2006	887.040	1,283.405	993.949	0.856	508.355	0.714	1,307.019	-20.216	46.56	3.81
2007	828.477	1,241.652	963.006	1.422	465.821	1.442	1,266.507	-15.719	45.11	3.24
2008	820.374	1,242.741	981.809	1.917	420.384	0.259	1,293.071	-18.110	46.06	4.11
2009	745.523	1,175.459	921.863	0.872	401.677	0.829	1,207.097	-12.637	43.00	3.04
2010	830.119	1,278.736	987.123	1.738	424.206	1.029	1,315.113	-19.390	46.85	4.34
Total	859.781	1,271.635	985.837	1.778	475.607	0.966	1,300.798	-18.652	46.34	3.75

Note: Entropies and transmissions in millibits of information.

Table 7-4. Mutual information, entropies, efficiency, and transmission power in the West African national innovation systems

Country	H_{UI}	H_{UG}	H_{IG}	T_{UI}	T_{UG}	T_{IG}	H_{UIG}	T_{UIG}	η(%)	τ(%)
Benin	999.693	1,292.234	980.815	0.000	688.274	0.000	1,292.234	0.000	46.03	0.00
Burkina Faso	955.336	1,255.310	958.565	0.375	542.153	1.057	1,255.310	-5.503	44.72	1.00
Cape Verde	1,241.939	1362.402	1,222.163	42.849	525.696	99.351	1,362.402	-216.902	48.53	24.51
Cote d'Ivoire	1,003.003	1335.648	999.688	0.635	654.285	0.660	1,335.648	-5.731	47.58	0.87
Gambia	305.401	358.848	203.43	0.000	149.982	0.000	358.848	0.000	12.78	0.00
Ghana	1,047.245	143.309	1,085.431	7.114	529.522	5.228	1,464.740	-47.321	52.18	8.03
Guinea	920.677	1,099.200	841.019	5.678	496.540	28.368	1,099.200	-65.955	39.15	11.06
Guinea Bissau	572.369	706.835	383.464	0.000	248.998	0.000	706.835	0.000	25.18	0.00
Liberia	976.021	1,288.650	902.393	0.00	589.764	0.000	1,288.650	0.000	45.9	0.00
Mali	999.427	1,301.385	990.104	0.000	688.146	0.000	1,301.385	0.000	46.36	0.00
Niger	976.946	1,135.453	957.932	0.000	799.336	0.000	1,135.543	0.000	40.45	0.00
Nigeria	696.480	1,027.455	850.400	9.091	370.181	0.530	1,066.119	-31.148	37.98	7.58
Senegal	1,011.925	1,318.699	1,002.108	1.293	670.551	1.469	1,318.688	-11.011	46.97	1.61
Sierra Leone	1,106.157	1,386.951	1,085.815	15.927	594.332	21.284	1,386.951	-86.739	49.4	12.08
Togo	1,007.537	1,279.648	1,020.604	2.728	707.221	2.195	1,279.648	-18.175	45.58	2.49

Note : Entropies and mutual information in millibits of information – Transmission power as percentage.

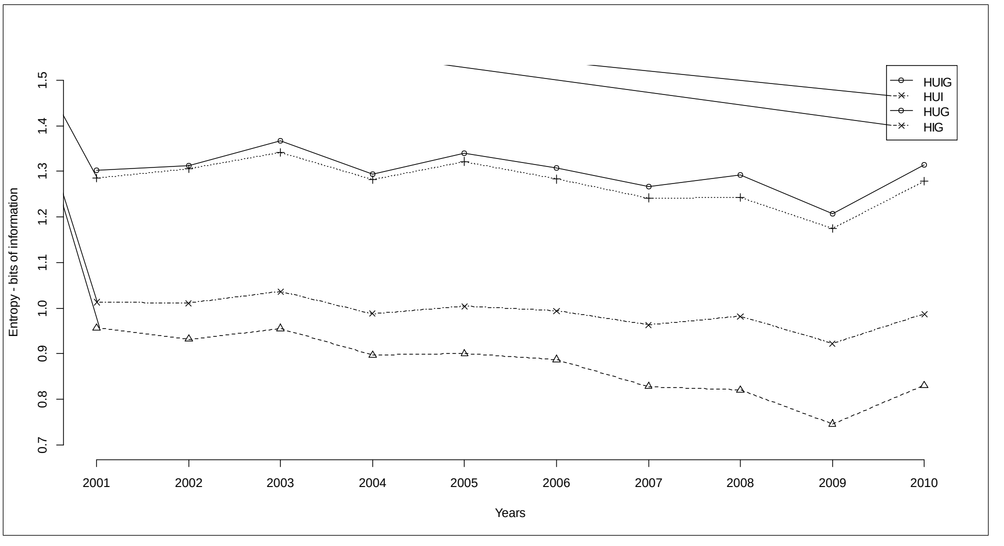

Figure 7-2 Relative positions of H_{UI}, H_{UG}, H_{IG} and H_{UIG}

In the countries with null industrial output, the bilateral transmissions T_{UI} and T_{IG} are null; further, the trilateral transmission T_{UIG} is null. These results suggest that regarding research output, there is no knowledge transfer between industrial sector and the two others on the one hand and on the other hand, there is no information transfer between the three actors. Only Nigeria and Ghana show industrial collaboration with University (U) and Government (G) sectors; however, Ghana has no University-Industry-Government (UIG) relations. These two countries have the higher industrial contribution to Gross domestic product (GDP). On its own, Nigeria counts one half the region industries and contributed 40% of the regional GDP in 2006 (ECOWAS Commission, 2010a, p. 17), that means industrial activities is better developed in this country than elsewhere in West Africa.

It is expected that University is ranked first with respect to scientific output, because of the flow of doctoral students and scholars' publishing activities. At national level, except Ghana, Nigeria and Togo, University output is lower than governmental one, presumably because hospital which is also the affiliation of some scholars, are categorized into governmental body. However, Nigeria on its own produces half the regional output (Mêgnigbêto, 2013a, 2013d, 2013f) and its University share is the largest compared with other countries; consequently, the regional output is balanced in favour of University. The ranking of countries with respect to transmission and transmission power yields the same result, leaving at the rear the six countries with null industrial output.[65] In comparison with other countries, taking into account a ten-year period (Mêgnigbêto, 2014a, pp. 288–289), West Africa performs less than individual countries like USA, UK, Germany, France, Russia, India, Brazil, and South Korea for their one-year data. Indeed, these countries transmission and transmission power for the year 2001 are respectively – 74.417 millibits and 0.229, – 63.118 millibits and 0.211, – 43.37 millibits and 0.186, – 52.123 millibits and 0.184, – 24.206 millibits and 0.093, – 78.106 millibits and 0.169, – 22.438 millibits and 0.099, and – 253.382 millibits and 0.286. The synergy among innovation actors over a ten-year period in West Africa based on scientific publications is less than that of these countries over one year.

One may notice that for countries with no industrial output, and thus no collaboration between Industry and other sectors (I = UI = IG = UIG = 0), the trilateral transmission (T_{UIG}) is null while not all bilateral transmissions (T_{UI}, T_{UG} and T_{IG}) are. In bilateral relations, transmission measures the level of independence between variables (cf. Batina et al., 2011). That is, if two variables are independent, the transmission between them is null. If more than two random variables are mutually independent, there are also pairwise independent (Cover & Thomas, 2006; Yeung, 2001, 2008). In a three-dimensional system, if the system's transmission is null, therefore, the variable are mutually independent, so there are pairwise independent (cf. Cover & Thomas, 2006; Yeung, 2001, 2008). However, our results show that in some cases, the three-dimensional transmission is null whereas not all bilateral transmission are (See Appendix 8). Normally, we should get $T_{UI} = T_{UG} = T_{IG} = 0$ each time $T_{UIG} = 0$. Leydesdorff (2014) explained this situation by the fact that the mutual information in three or more dimensions is not a Shannon-type information and that is such a system, loops are involved that may generate redundancies (Leydesdorff, 2014; Leydesdorff & Ivanova, 2014). Krippendorff (2009a, p. 676) added that interactions with loops entail positive or negative redundancies; he claimed that this is a proof algebra is not able to get unique interactions among three or more variables for the simple raison that probabilities do not take care of circular interactions which begin with three or more variables (Krippendorff, 2009a, 2009b, 2014). Leydesdorff and Park al. (2014) supported however that the mutual information due to the change of its sign measures both the "the necessarily positive interaction information and the potentially negative correlational information".

Another remark is that except the two countries with UI and IG relations (Ghana and Nigeria, in bold in Table 7-4 where H_{UG} is less than H_{UIG}, H_{UIG} equals H_{UG} elsewhere. A mathematical demonstration is given in Appendix 8. This result suggests that the trilateral University-Industry-Government system operates like a simple bilateral University-Government one. Therefore, one may expect T_{UIG} to be positive as in the case of a two-dimensional system and T_{UI} equal to T_{UG}, as if the presence of industrial

[65] The list in decreasing order of mutual information or transmission power is: Cape Verde, Sierra Leone, Guinea, Ghana, Nigeria, Togo, Senegal, Burkina Faso, Cote d'Ivoire, Benin, Gambia, Guinea Bissau, Liberia, Mali, Niger.

output or relations with University or Government had no effect; but calculations give $T_{UIG} \leq 0$. Leydesdorff and Ivanova (2014, p. 390) gave an explanation:

> A spurious correlation can reduce uncertainty, as when two parents reduce uncertainty for a child by providing mutually consistent answers to questions. (…). The marriage can be considered as a latent construct in which the child plays a role without constituting it. Similarly, in University–Industry–Government relations, a strong existing relation between two of the partners can make a difference for the third.

7.6. Conclusion

This chapter aimed at measuring knowledge flow between innovation actors in the West African region. It uses publications as unit of analysis and computes data on the collaboration between the three Triple Helix innovation model actors that are University, Industry and Government. The publications data were collected from Web of Science for the 15 West African countries. We used the mutual information and the transmission power as indicators of knowledge flow. These indicators were computed for both the region and individual countries. We found that at the regional level, University is the biggest knowledge producer followed by Government and Industry in that order; however, at national level, Government is the biggest information producer in majority of the countries. Industrial sector output is weak both at regional and individual countries level. It is even null in some countries.

The mutual information values computed indicated the existence of synergy between the three actors, both at regional and national level. However, they are too low to allow a fluent knowledge circulation among actors; indeed, at the regional level the mutual information varies from − 32 to − 12 millibits of information; at individual countries level, it is null in six countries, takes a value less than −20 millibits in four countries and more than − 40 millibits in five countries; Cape Verde has the highest negative mutual information (− 217 millibits of information). Consequently, the annual transmission power which indicates the efficiency of the mutual information has weak values at the regional level (2 to 5%). This indicator showed a large variation at national level: it is null in the six countries, takes a value less than 10% in six countries and more than 10% in the three remaining countries, with Cape Verde having the highest value (25%).

According to Leydesdorff (e.g. 2008, 2010b), the mutual information indicate how knowledge-based an economy is. We argue that the transmission power, as an indicator derived from the mutual information also is a candidate indicator for the measurement of the knowledge-based economy.

8. The transmission power and the knowledge-based economy

The Triple Helix hypothesises that the University-Industry-Government relationship maintains a knowledge infrastructure that allows producing knowledge of which circulation engenders innovation. Because knowledge is created by researchers, there is a relation between research and innovation. How does knowledge creation relate to knowledge economy? In this chapter we used the transmission power as knowledge sharing indicators. We test for any relation it has with some indicators used to measure knowledge-based economy. The case study is based on six OECD countries namely the United States, Canada, France, Germany, Japan and South Korea.

This chapter is based on conference paper presented at the Journées Scientifiques Internationales de Lomé in 2014 (Mêgnigbêto, 2014e), a short paper published in ISSI Newsletter (Mêgnigbêto, 2015c) and an article under review (Mêgnigbêto, under review).

8.1. Introduction

The preponderant role knowledge has been playing for mankind ended the traditional economy based on the industrial production; in the same way, it has inaugurated the post-industrial economy and made intangible assets to be included in economies performance, so that the term “knowledge-based economy” has been used to characterize nowadays’ economies. According to the Organisation for the Economic Co-Operation and Development (OECD), a knowledge-based economy is the one which is “directly based on the production, distribution and use of knowledge and information” (OECD, 1996, p. 7). It implies that economic growth, wealth creation and employment are driven essentially through the production, distribution and use of knowledge (APEC Economic Committee, 2000). Since the term has been coined, conferences were held, e.g. by OECD (OECD & National Science Foundation, 1999) or by the European Union (European Commission - EUROSTAT, 2006). They aimed at deepening the concept, defining its contents and contours and discussing its measurement. Frameworks were set up to provide the concept with indicators mainly by international organisations (APEC Economic Committee, 2000; Chen & Dahlman, 2005; OECD, 1996) (cf. Appendix 9) and enable its measurement so that economies could be assessed and compared. Strategies and plans were formulated at international, regional and national levels in order to promote economies towards knowledge-based ones. (e.g. APEC Economic Committee, 2000; Australian Bureau of Statistics & Trewin, 2002; European Commission, 2010a; United Nations Economic Commission for Europe, 2002); publications are released regularly that assess how economies are knowledge-based (e.g. European Commission, 2014; OECD, 2013).

The publications that attempted to measure to which extent an economy is knowledge-based used a range of indicators that vary from one version to another and also from one institution to another (cf. Godin (2006a) for the case of OECD; and Karahan (2012) for the overview of the indicators used by international organizations like OECD, the World Bank, the Asia-Pacific Economic Cooperation and the European Union). Therefore, there is not yet a consensus on which indicators to use to measure a knowledge-based economy. However, economy growth is the result of interactions between innovation actors of which the main ones are University, Industry and Government.

Etzkowitz and Leydesdorff (1995) noted that the relations and the role of these actors are being changing; each are exerting the role of the another (Leydesdorff & Etzkowitz, 2001). Therefore, the traditional role of these actors is changing. Etzkowitz and Leydesdorff (1995) elaborated the theory of Triple Helix of University-Industry-Government relationships to model these changes and their impact on economic growth, and hence on development and social welfare. The interactions between the three actors provide a knowledge infrastructure necessary to the knowledge-based economy (Leydesdorff, 2003, 2008, p. 401). In order to provide the theory with a measure, Leydesdorff (2003) elaborated the mutual information as an indicator of the University, Industry and Government relationships and hence, an indicator of the extent to which an economy can be characterized as a knowledge-based economy (Leydesdorff, 2008, 2010b). Many studies used the mutual information to assess the relations between University, Industry and Government in different parts of the world (e.g. Khan & Park, 2011; Leydesdorff et al., 2013; Leydesdorff & Sun, 2009; Mêgnigbêto, 2013e) or to assess the knowledge base of economies (e.g. Leydesdorff et al., 2015; Leydesdorff & Zhou, 2013; Park et al., 2005). Mêgnigbêto (2014a) proposed the transmission power as the efficiency of the mutual information and affirmed that it is more suitable for comparison purpose. The transmission power was used to assess the knowledge flow within the West African innovations systems, both at national and regional levels (Mêgnigbêto, 2014b, 2014c); it was also used to compare the knowledge production profiles of six OECD countries (Mêgnigbêto, 2015c). Jointly with other indicators, it helped in studying the Norwegian innovation system both at national and county level, based on data including the number of establishments in geographical, organizational, and technological dimensions over a 13-year period (Ivanova, Strand, & Leydesdorff, 2014).

Innovation has an incidence on economic growth and social wellbeing (Dolan & Metcalfe, 2012); besides, the level of development of a region depends on the level of research product consumption (Mueller, 2006). Therefore, we need to test whether the transmission power could be used as an indicator of research, research collaboration or innovation. In other words, our objective is to test whether there is any correlation between transmission power and the level of development of a country (or region). This study seeks to answer the following research question: does the transmission power measure the extent to which an economy is knowledge-based?

The aim of this study is to test any correlation between the transmission power and some indicators used to measure knowledge economy. Any correlation found could mean that the transmission power measures the same things as the considered indicator; the absence of correlation could mean that the transmission power really captures a dynamic that is missing from other indicators.

The chapter is organised as follows: first, a background on the transmission power is given; then the selected countries and indicators were dealt with in a third step, the data source and collection were described, and finally, results are presented and discussed in subsequent sections.

8.2. How to measure the knowledge economy? A review of literature

The initiatives towards measuring the knowledge-based economy were mainly taken by international organisations like the OECD, the World Bank, the European Union, the Asia-Pacific Economic Committee or the United Nations. Some nations also contributed. In fact, the economy has been always based on knowledge; indeed, even in the so-called industrial economy (or traditional economy) humans needed knowledge in order to transform natural resources and contribute to economic growth, "because everything we do depends on knowledge" (World Bank, 1999, p. 16).

The OECD has published several reports related to the knowledge-based economy (e.g. OECD, 1996, 1999, 2013). These reports used up to sixty indicators with variations from one publication to another; for example, Godin (2006a, p. 18) noted that the OECD collected up to sixty indicators aiming at measuring the knowledge-based economy. The Word Bank devoted its 1998 annual development report to "knowledge for development" (World Bank, 1999). A few years later, it established the Knowledge Economy Framework (Chen & Dahlman, 2005) which built two indicators: the Knowledge Economy Index (KEI) and the Knowledge Index (KI). The KI measures a country's ability to generate, adopt and diffuse knowledge; it is an indication of the overall potential for knowledge development in a given country. The KEI takes into account whether the environment is conducive for knowledge to be used effectively for economic development; it is an aggregate index that represents the overall level of development of a country or region in relation to the knowledge economy. The two indexes are based on four pillars: i) economic incentive and institutional regime, ii) education and human resources, iii) innovation system and iv) information and communications technologies. These indicators are used by the World Bank to rank economies regularly. The Statistical Office of the European Union regularly publishes statistics on innovations and knowledge-based economy.

The Asian-Pacific Economic Cooperation started by defining the idealised knowledge-based economy under the name of Nikuda, and fixed its characteristics (APEC Economic Committee, 2000, pp. 3–16). It distinguished into four categories[66] indicators that qualify a “fully developed knowledge-based economy” (APEC Economic Committee, 2000, p. 16). However, the document recognized that the given indicators are too idealistic and that not all its members could provide the statistics; then a sub-set was extracted and presented (p 19, Table I-3-1) following the knowledge chain (acquisition, creation, dissemination and use).

The European Commission also published reports on its Member States’ knowledge-based economy. In the 2010 innovation scoreboard (European Commission, 2010b), it published twenty-six statistics in five categories that are, i) innovation drivers (5), ii) knowledge creation (5), iii) innovation and entrepreneurship (6), iv) application (5) and v) intellectual property (5). More recently, the European Commission has set up a composite index, the Summary Innovation Index – which summarizes the performance of a range of 25 different indicators (European Commission, 2014, p. 8). The objective is no longer a direct measurement of the knowledge-based economy but rather innovation performance.

The United Nations Economic Commission for Europe (2002) defined a framework to measure the knowledge-based economy. It suggested the Global Knowledge-Based Economy Index (GKEI) as a measure. The GKEI has tree sub-indexes: i) technology (TGKEI), ii) public institutions (PGKEI) and iii) macroeconomic environment (MGKEI) (p. 55 ff). The main weakness in the UNECE knowledge-based economy framework is that the selected indicators relate all to ICTs while “knowledge economy does not necessarily revolve around high technology or information technology” (Suh, Chen, Korea Development Institute, & The World Bank Institute, 2007).

Apart from efforts by international organizations to define indicators to assess a knowledge-based economy, national institutions also have contributed to the debate. For example, the Australian Bureau of Statistics defined a framework following the same methodology as the OECD, the World Bank, the APEC and the EU. All the frameworks referred to above used a “suite-of-indicators”. Godin (2006a) noted that none of the indicators intended to contribute to the measurement of the knowledge based economy is really new; they all existed before the concept and have been used to measure a particular aspect of the “traditional economy” for decades.

Individual researchers have also proposed indicators. For example, Arvanitidis and Petrakos (2011, p. 25) developed the Economic Dynamism Indicator, a composite index. The Centre for International Development (CID) at Harvard University proposed 19 indicators in 5 areas that are i) networked access, ii) networked

[66] The categories are: i) innovation system, ii) human resource development, ii) information and communication technologies infrastructure and iv) business environment.

learning, iii) networked society, iv) networked economy and v) networked policy).[67] Leydesdorff (2003) on the one hand and Leydesdorff and Ivanova (2014) on the other hand respectively proposed the mutual information or transmission and the mutual redundancy as a measure of the interactions among innovation system actors, and hence, of a knowledge-based economy. These two measures are derived from Shannon's (1948) information theory.

In summary, even though frameworks are produced by international or national institutions or researchers about the knowledge-based economy, there is not yet an internationally accepted indicator to capture the concept. What the frameworks have in common, however, is the omnipresence of information or knowledge chain that includes production, acquisition, dissemination and uses. Considering that the mutual information is a scalar (Leydesdorff & Ivanova, 2014), that it indicates the quantity of information common to two variables (Shannon, 1948) and is used to measure how knowledge is shared within a system of variables (cf. Leydesdorff, 2010b; Leydesdorff & Zhou, 2013), Mêgnigbêto (2014a) determined the upper and lower bounds to the mutual information that vary depending on the system's variables; then he proposed its normalisation under the name transmission power. Because the transmission power has been used to study how an economy is knowledge-based, it is needed to test any relation with indicators used to study the knowledge-based economy.

8.3. Methods and data

8.3.1. Mutual information and transmission power

The mutual information is borrowed from the Shannon's (1948) information theory of which central notion is entropy. The entropy is the quantity of information contained in a variable. If an event occurs with the probability p, its entropy is (cf. Shannon, 1948):

$$\mathrm{H} = -\mathrm{p} \times \log_2 \mathrm{p} - (1-\mathrm{p}) \times \log_2(1-\mathrm{p}) \qquad (8\text{-}1)$$

where $\log_2$ is the logarithm to the base 2; the entropy may however be computed to other bases e.g. 3, 4, ..., 10). More generally, if $\mathrm{X} = (\mathrm{x}_1, \mathrm{x}_2, \dots, \mathrm{x}_\mathrm{n})$ is a random variable and its components occur with the probabilities $\mathrm{p}_1, \mathrm{p}_2, \dots, \mathrm{p}_\mathrm{n}$ respectively, with $\sum_{i=1}^{n} p_i = 1$then the entropy generated by X is (Shannon, 1948; Shannon & Weaver, 1949)

$$\mathrm{H}_\mathrm{X} = -\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{p}_\mathrm{i} \times \log_2 \mathrm{p}_\mathrm{i} \qquad (8\text{-}2)$$

For two random variables X and Y, if H_X is the entropy of X and H_Y that of Y, the joint entropy H_{XY} of the system of the two variables is equal to the entropy H_X plus H_Y minus the entropy of the overlay of X and Y. The latter is called "rate of transmission"

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[67] http://www.readinessguide.org

(Shannon, 1948) or mutual information (Cover & Thomas, 2006; Leydesdorff, 2003, 2008; Mori, 2006; Yeung, 2001, 2008) between X and Y. The relations between the transmission, T_{XY}, the joint entropy H_{XY} and the marginal entropies of the variables, H_X and $H_{Y,}$ are (Shannon, 1948):

$$H_{XY} = H_X + H_Y - T_{XY} \tag{8-3}$$

and

$$T_{XY} = H_X + H_Y - H_{XY} \tag{8-4}$$

In case of three random variables X, Y and Z (three dimensions), the relations between the system's entropy, its mutual information, the marginal entropies and the bilateral mutual informations are given by (cf. Abramson, 1963; Leydesdorff, 2003; Theil, 1972):

$$H_{XYZ} = H_X + H_Y + H_Z - T_{XY} - T_{XZ} - T_{YZ} + T_{XYZ} \qquad \text{(8-5))}$$

and

$$T_{XYZ} = H_X + H_Y + H_Z - H_{XY} - H_{YZ} - H_{XZ} + H_{XYZ} \tag{8-6}$$

The transmission power of a system is the fraction of the maximum value of the mutual information devoted to information sharing in the system; it represents the share of the "total configurational information" really produced in the system. In other words, it measures the efficiency of the mutual information.

For a three-dimensional system, Mêgnigbêto (2014a) distinguished two types of transmission power: the first one (τ_1) when the transmission is negative, and the second (τ_2) when the transmission is positive:

$$\tau = \begin{cases} \tau_1 = \dfrac{T_{XYZ}}{H_{XYZ} - H_X - H_Y - H_Z} \text{ if} T_{XYZ} < 0 \\ \tau_2 = \dfrac{T_{XYZ}}{H_{XYZ}} \text{ if} T_{XYZ} > 0 \\ 0 \text{ if} T_{XYZ} = 0 \end{cases} \tag{8-7}$$

The transmission power varies from 0 to 1; it is dimensionless and may be expressed as a percentage (Mêgnigbêto, 2014a).

8.3.2. *Selected countries and indicators*

For the purpose of this article, we collect data on six countries over a 10-year period (2001-2010). All the countries are members of the OECD: two from the American continent (USA and Canada), two from Europe (France and Germany) and two from Asia (Japan and South Korea). This choice is guided by the fact that the OECD has been playing a crucial role in the dissemination of the term knowledge-based economy (Godin, 2006a) and also regularly provides statistics on different aspects of its Member States' economy. The APEC Economic Committee's (2000, p. 19 Table I-3-1) matrix of indicators was used as a starting point of the process of indicator selection; indeed, this matrix distinguishes indicators according to the knowledge chain (acquisition, creation, uses and dissemination). As far as our research is concerned, mutual information is derived from research output and research collaboration data. By doing research, researchers produce information and knowledge; by collaboration means, they increase their productivity (Katz & Martin, 1997) and share information and knowledge (Guns & Rousseau, 2014; Katz & Martin, 1997; Olmeda-Gómez et al., 2008). Therefore, we can consider mutual information as an indicator of information and knowledge production on the one hand, and information and knowledge sharing on the other hand. According to Liu (2011, p. 87 ff) and Liu et al. (2013) knowledge diffusion starts with the 'act of publication' and the citations publications received. Clearly, the mutual information, and therefore, the transmission power, do not intervene at the diffusion side of knowledge or information; it intervenes on neither the acquisition side nor the use side; but rather on the production and sharing side only.

The APEC matrix retained four indicators in four categories for the knowledge production. They are the Gross Domestic Expenditure for Research and Development (GERD) as percentage of Gross Domestic Product (GDP), the natural science graduates per annum, the Business Expenditure for Research and Development (BERD), the number of researchers per capita and the Patents awarded in the US per annum. Hence, from the APEC's matrix, we retain the GERD as percentage of GDP and the number of researchers; these indicators are also present in the framework proposed by the OECD, the World Bank and the European Union. Karahan (2012) distinguished them as input indicators. Some indicators are usually used to measure economic and social development; we selected three considered as output indicators; they are: i) the Human Development Index (HDI), ii) the Gross Domestic Product growth rate and iii) the Gross Domestic Product per capita. The HDI is a composite index measuring average achievement in three basic dimensions of human development: i) a long and healthy life, ii) knowledge and iii) a decent standard of living (UNDP, 2013, p. 147). The last two indicators measure the growth in the domestic wealth production in a given area. Finally, we select the Total Factor Productivity (TFP) also called Multi-Factor Productivity (MFP) because it represents the "part of GDP growth that cannot be explained by changes in labour and capital inputs".[68]

We should stress that the HDI time series cover only the period 2005-2010. Indeed the indicator is provided by interval of 5 years from 1980 to 2000 and for each year, from 2005 to 2013, in the recent Human Development Report (UNDP, 2014). But when referred to previous versions of the report, the HDI for a particular country and year is not the same from one report to another, because the methodology in

[68] https://data.oecd.org/lprdty/multifactor-productivity.htm

computing the indicator and the indicators composing it varies over time; therefore, the UNDP advises against comparison of HDI across years (UNDP, 2005, p. 212). So, for methodological reasons, we restrict data to the period 2005-2010 for the HDI.

In summary, the six selected indicators we are comparing the transmission power to are GERD (OECD, 2014a), number of researchers (OECD, 2014b) , GDP growth rate, GDP per capita (OECD, 2015a), HDI (UNDP, 2014, Table 2) and TFP (OECD, 2015b).

8.3.3. Research data collection

Research collaboration is recognized as crucial for knowledge production and innovation (OECD, 2010, p. 98); it may cover several aspects. Even though research collaboration doesn't always yield publications, we consider co-authorship as its indicator, because it has been widely used in Academia (Abbassi et al., 2012; Bordons & Gomez, 2000; Katz & Martin, 1997; Olmeda-Gómez et al., 2008). It entails the tacit transfer of information and knowledge (Olmeda-Gómez et al., 2008) and ensures diffusion of ideas and knowledge circulation (Guns & Rousseau, 2014). The Triple Helix thesis relies on research collaboration.

We collect data over a ten-year period (2001-2010) on the selected countries' University, Industry and Government research output and collaboration through the Web of Science. The databases searched were Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index-Science (CPCI-S), Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH). The search strategy consists of eleven steps for each country, adapted from Ye et al. (2013), based on the search strings previously developed and tested by Leydesdorff (2003, p. 458) and Park et al. (2005, p. 13 ff):

#1: CU=COUNTRY and PY=2001-2010: selection of all the scientific output of COUNTRY over the period 2001-2010;

#2: PY=2001-2010 AND AD=(COUNTRY SAME (UNIV* OR COLL* OR ECOLE)): selection of all University output of COUNTRY over the period 2001-2010;

#3: PY=2001-2010 AND AD=(COUNTRY SAME (GMBH* OR CORP* OR LTD* OR AG*)) : selection of all Industry output of COUNTRY over the period 2001-2010;

#4: PY=2001-2010 AND AD=(COUNTRY SAME (NATL* OR NACL* OR NAZL* OR GOVT* OR MINIST* OR ACAD* OR NIH*)) : selection of all governmental output of COUNTRY over the period 2001-2010 ;

#5: PY=2001-2010 AND AD=(COUNTRY SAME (NATL* OR NACL* OR NAZL* OR GOVT* OR MINIST* OR ACAD* OR NIH*) SAME (UNIV* OR COLL* OR ECOLE)): selection of output of COUNTRY government and University share over the period 2001-2010;

#6: PY=2001-2010 AND AD=(COUNTRY SAME (NATL* OR NACL* OR NAZL* OR GOVT* OR MINIST* OR ACAD* OR NIH*) SAME (GMBH* OR CORP* OR LTD* OR AG*)) :

selection of output of COUNTRY Government and Industry share over the period 2001-2010;

#7: #4 NOT #5 NOT #6: selection of governmental output only over the period 2001-2010;

#8: #2 AND #3: selection of University and Industry collaboration output over the period 2001-2010;

#9: #2 AND #7: selection of University and Government collaboration output over the period 2001-2010;

#10: #3 AND #7: selection of Industry and Government collaboration output over the period 2001-2010;

#11: #2 AND #3 AND #7; selection of University, Industry and Government collaboration output over the period 2001-2010.

8.3.4. Computation of indicators

The results of each stage were entered into a worksheet; and on a second worksheet, formulas are entered to compute University, Industry and Government sectorial output and other bilateral and trilateral collaboration data. We coded a PHP programme that computes the sectorial entropies, the bilateral entropies and transmission, and the trilateral entropies and transmission according to the formulas given above (cf. Appendix 10) Furthermore, the programme calculates the transmission power and the efficiency at the trilateral level.

8.4. Results

Analyses are presented at the following three levels: i) mutual information and transmission power level, ii) selected indicators level and iii) selected countries level.

8.4.1. Mutual information and transmission power of selected countries

The mutual information and the transmission power of the selected countries are computed in Table 8-1. Figure 8-1plots the time series of the mutual information of the selected countries over the period of study (2001-2010). It shows that the mutual information values are negative for all the countries meaning that synergy exists within the selected national innovation system. Because the more negative the mutual information, the more there is synergy, we consider the absolute values of the time series. It results that the South Korean innovation system has gained in synergy over time (the absolute value of its mutual information has increased over time) and that the five other countries' innovation systems have lost synergy (the absolute value of their mutual information has decreased over time). Germany is in the lowest position, followed by South Korea; Canada and USA, the systems of which exhibit approximately the same values over the period, occupy respectively the third and second positions. The French mutual information is higher than that of Japan until 2007 where the two countries display an equal value; then, the synergy into the Japanese innovation system became higher.

Regarding the transmission power (Figure 8-2), Japan keeps the first place, far ahead of the five remaining countries; France is still the second best performing system but reduces the gap with its successors; Canada also keeps the third place. Even though the USA begins the period with the fourth place, it has been caught up by South Korea in 2004 which competed with it until 2007 where it took the fourth place lagging the USA at the fifth position. Over all the period, Germany keeps the rear with respect to the transmission power. Whereas the two Asian countries exhibit an increasing trend with respect to the transmission power, the other countries show the reverse (Table 8-2).

In summary, the synergy within the innovations systems operates largely in Japan and France than elsewhere; the USA and Canada present likely similar pattern; the South Korean innovation system has gained in synergy while the five others have lost. Germany seems to have the least integrated innovation system as measured by the indicators we used.

8.4.2. Selected indicators level analyses

The plots of GERD against transmission power for the selected countries are presented in Figure 8-3. Three countries exhibit a negative correlation between transmission power and GERD. They are USA, France and Germany. Whereas the correlation is strong in the case of Germany ($r = -0.9$) and France ($r = -0.75$), the two European countries, it is weak in the case of USA ($r = -0.26$). Conversely, Canada and Japan show a strong positive correlation between transmission power and GERD ($r = 0.78$ and $r = 0.85$ respectively) while, South Korea displays a moderate positive correlation between the two variables.

Japan and South Korea, the two Asian countries, show a positive moderate correlation between transmission power and number of researchers ($r = 0.4$ and $r = 0.66$ respectively). The four remaining countries (France, Germany, USA and Canada) exhibit a negative correlation with regard to the two indicators. However, the negative correlation is less pronounced in the case of France than that of the three others countries where it is strong (Figure 8-4). The situation depicted by the plot of GDP growth rate against transmission power is exactly the opposite of that of transmission power against number of researchers. Indeed, the two Asian countries, Japan and South Korea, show a negative correlation ($r = -0.17$ and $r = -0.44$) whereas the four other countries, which are American (USA, and Canada) and European (France and Germany) show a positive correlation. If the American countries show a weak correlation, the European ones exhibit a moderate to strong correlation between transmission power and GDP growth rate (Figure 8-5).

GDP per capita and transmission power on the one hand and HDI and transmission power on the other hand show the same pattern as numbers of researchers per thousand inhabitants and transmission power for all the selected countries: the Asian countries have a positive relation and the others a negative one (Figure 8-6 and Figure 8-7). With regard to TFP, the USA presents a strong negative correlation with the transmission power; Canada and Germany have a negative moderate or weak correlation; France exhibits a positive moderate correlation one while the two Asian countries show a positive strong correlation (Figure 8-8).

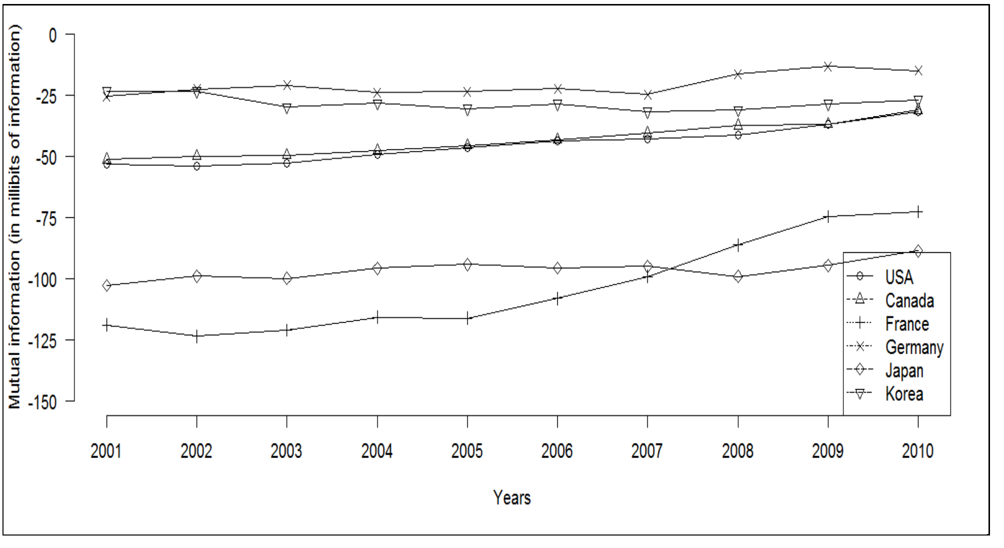


Figure 8-1 Mutual information of the UIG relationships of selected countries

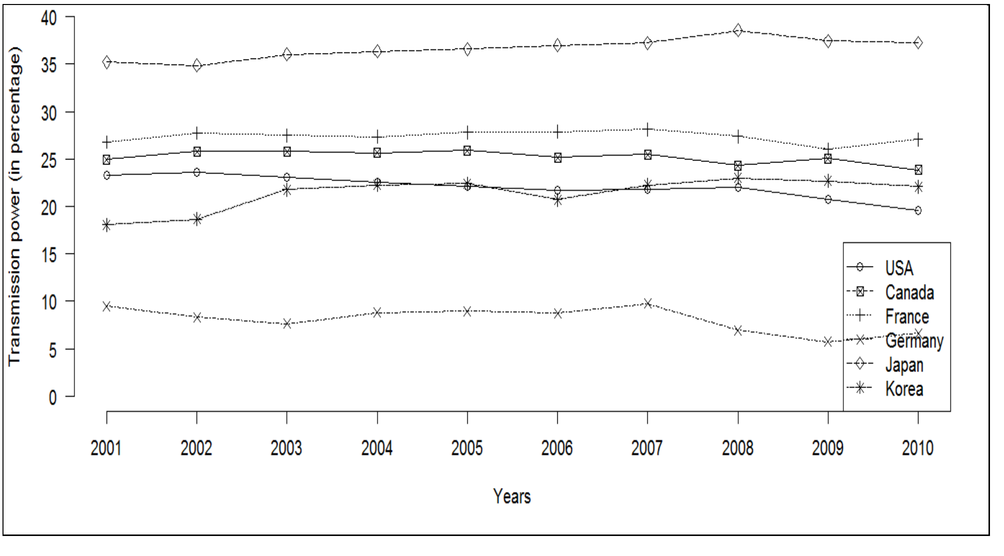


Figure 8-2 Transmission power of the UIG relationships of selected countries

Table 8-1. Mutual information (T_{UIG}, in millibits of information) and transmission power (τ, as percentage) of selected countries

Years	USA		Canada		France		Germany		Japan		South Korea	
	T_{UIG}	τ	T_{UIG}	τ	T_{UIG}	τ	T_{UIG}	τ	T_{UIG}	τ	T_{UIG}	τ
2001	−53.2	23.33	−51.259	24.96	−118.9	26.76	−25.494	9.49	−102.733	35.2	−23.301	18.07
2002	−54.148	23.56	−49.842	25.77	−123.529	27.73	−22.601	8.33	−98.907	34.84	−23.268	18.67
2003	−52.892	23.02	−49.437	25.82	−120.995	27.48	−20.999	7.62	−99.917	36	−29.877	21.77
2004	−49.091	22.56	−47.542	25.63	−115.757	27.32	−23.962	8.79	−95.809	36.35	−28.221	22.23
2005	−46.591	22.12	−45.574	25.9	−116.14	27.81	−23.476	8.96	−94.173	36.58	−30.537	22.42
2006	−43.453	21.72	−43.228	25.17	−107.999	27.87	−22.265	8.78	−95.602	36.98	−28.419	20.71
2007	−43.01	21.82	−40.607	25.46	−99.124	28.13	−24.713	9.77	−95.031	37.2	−31.649	22.24
2008	−41.316	21.96	−37.338	24.33	−86.299	27.39	−16.281	6.95	−99.057	38.56	−31.072	22.99
2009	−36.773	20.72	−36.724	25.04	−74.621	26.02	−13.17	5.76	−94.637	37.41	−28.412	22.69
2010	−31.938	19.57	−31.093	23.83	−72.583	27.06	−15.046	6.62	−88.644	37.25	−26.941	22.1

Table 8-2. Trend in the six countries' mutual information and transmission power series (t = 1 in 2001)

	USA	Canada	France	Germany	Japan	South Korea
Mutual information	$y = 2.38t - 58.32$ $R^2 = 0.95$	$y = 2.16t - 55.16$ $R^2 = 0.96$	$y = 6.t - 136.62$ $R^2 = 0.88$	$y = 1.11t - 26.88$ $R^2 = 0.59$	$y = 0.98t - 101.85$ $R^2 = 0.58$	$y = -0.5t - 25.41$ $R^2 = 0.27$
Transmission power	$y = -0.37t + 24.1$ $R^2 = 0.87$	$y = -0.145t + 26$ $R^2 = 0.42$	y = -–0.04t + 27.6 $R^2 = 0.05$	$y = -0.27t + 9.58$ $R^2 = 0.38$	$y = 0.32t + 34.9$ $R^2 = 0.76$	$y = 0.42t + 19.1$ $R^2 = 0.55$

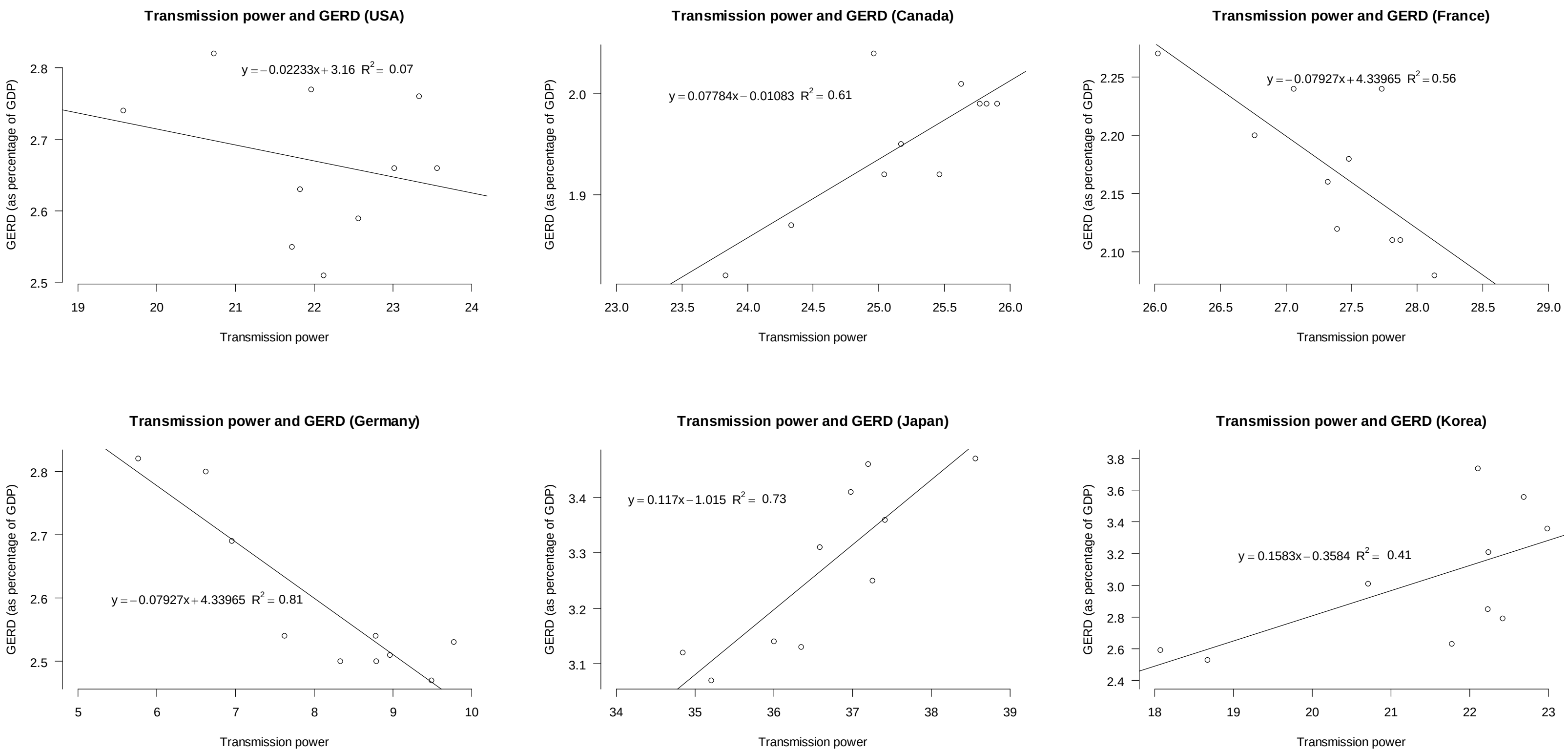


Figure 8-3 Transmission power and GERD of selected countries

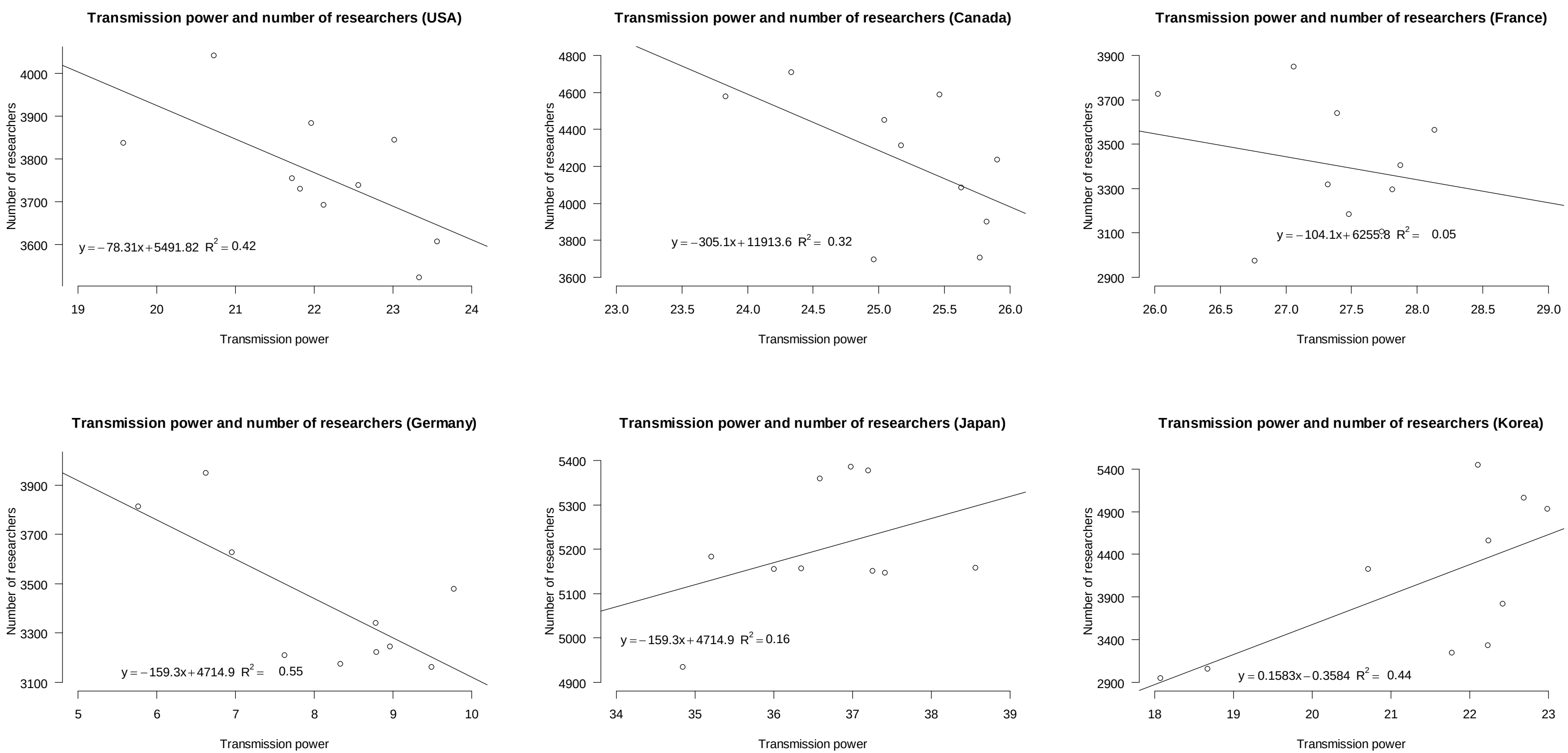


Figure 8-4 Transmission power and number of researchers of selected countries.

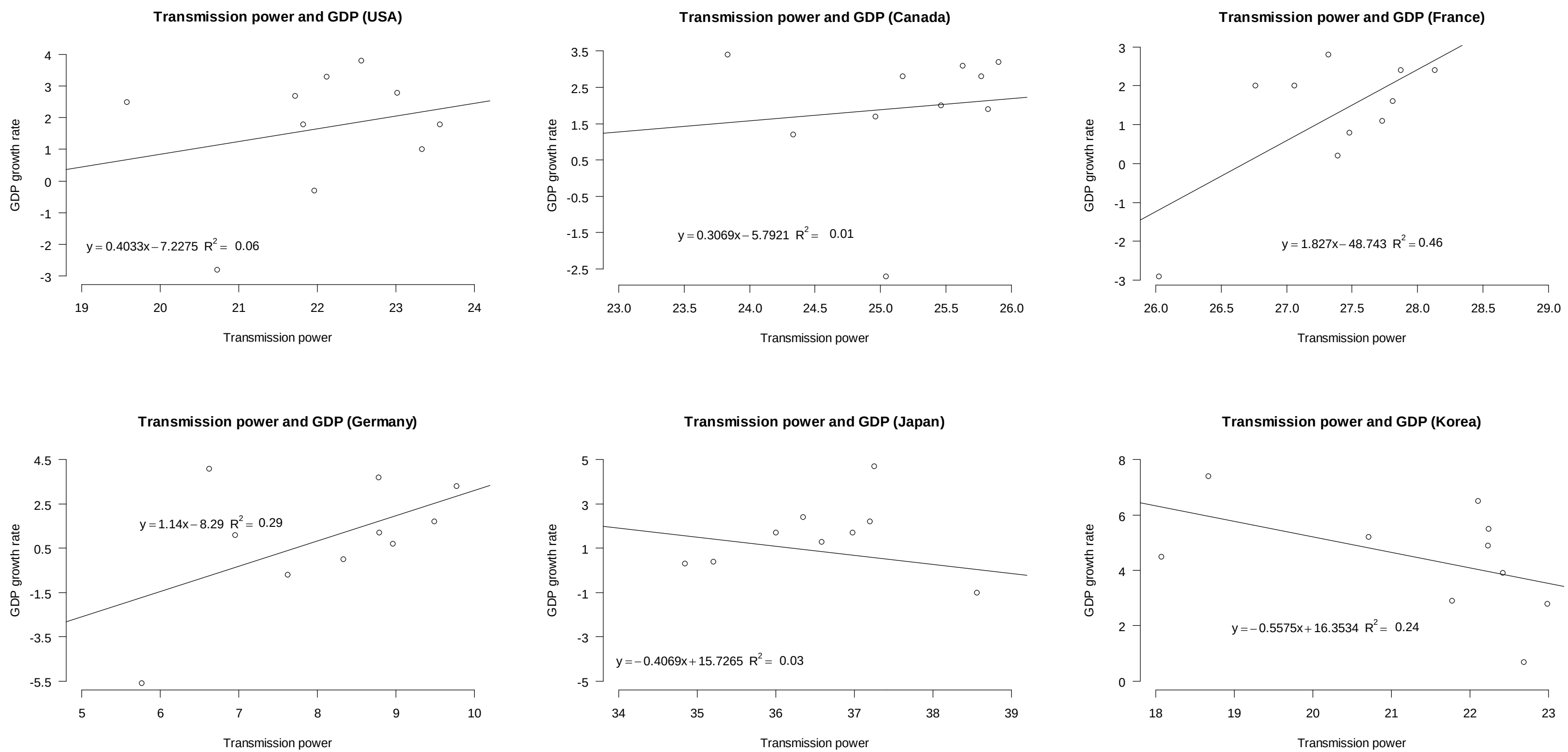


Figure 8-5 Transmission power and number of researchers of selected countries.

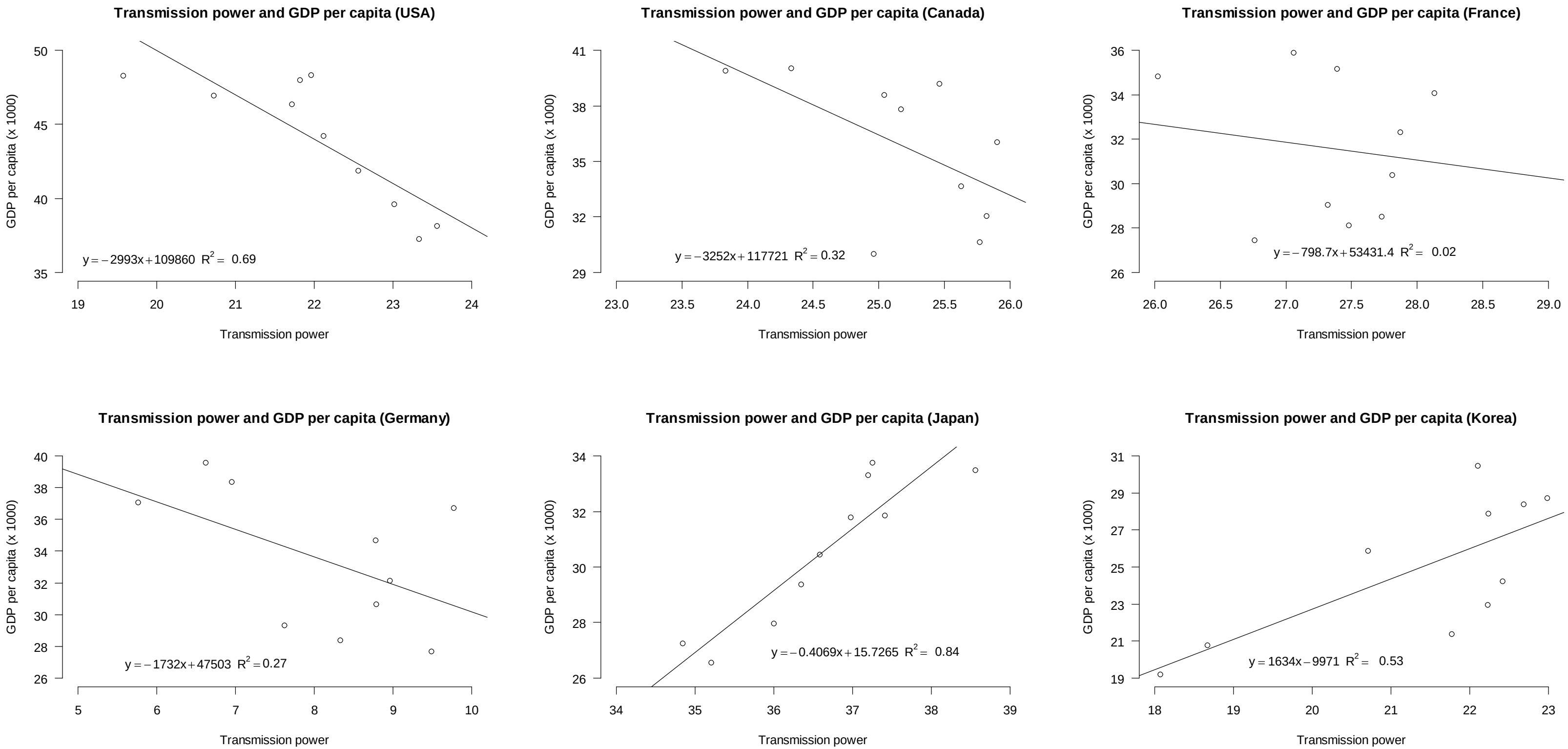


Figure 8-6 Transmission power and GDP per capita of selected countries.

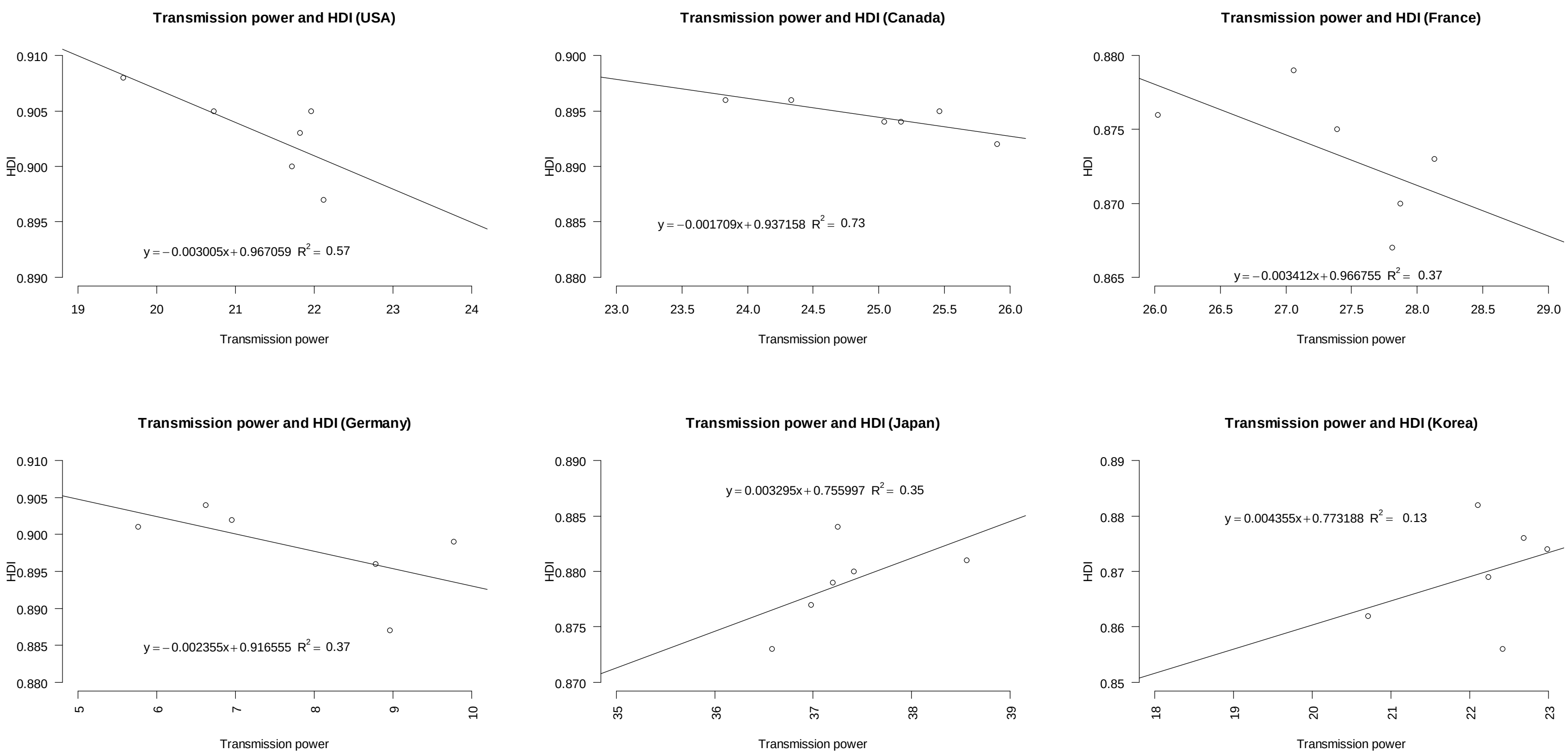


Figure 8-7 Transmission power and HDI of selected countries.

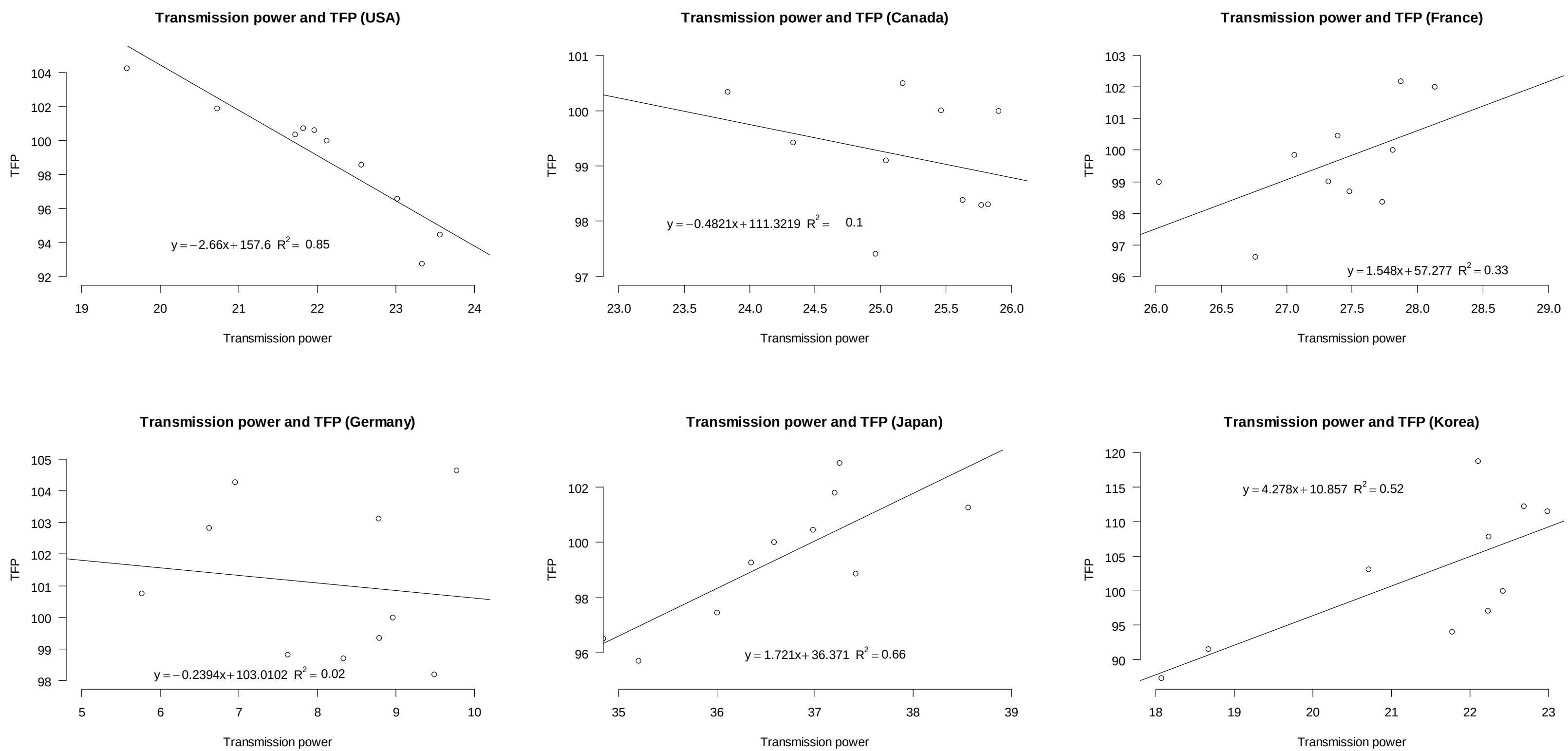


Figure 8-8 Transmission power and TFP of selected countries.

8.4.3. *Country level analysis*

Table 8-3 summarises the correlation coefficients of transmission power with the selected indicators for the selected countries. It shows that USA exhibits negative correlations between transmission power and five of the indicators and a positive moderate correlation between transmission power and GDP growth rate. Whereas the correlation between transmission power and GDP per capita on the one hand and transmission power and HDI is negative and strong (r = – 0.83 and r = – 0.75), it is moderate with GERD and the number of researchers. In the case of Canada, four indicators present a negative correlation with the transmission power; they are: number of researchers, GDP per capita and HDI. These correlations are moderate (GDP per capita and number of researchers) or strong (HDI). The Canadian transmission power has however a strong positive correlation with this country's GERD and a weak one with GDP growth rate, but has no correlation with TFP.

France has a negative strong correlation between transmission power and GERD, but a negative moderate correlation between transmission power and number of researchers on the one hand, and transmission power and GDP per capita on the other hand; but negative moderate correlation between transmission and HDI. Conversely, it shows a positive moderate correlation between transmission power and GDP growth rate and transmission power on the one hand and transmission power and TFP on the other hand. As far as Germany is concerned, transmission power shows a negative correlation with GERD, numbers of research, HDI and TFP and a positive correlation with GDP growth rate and GDP per capita. Japan and South Korea show the same patterns. The correlations are positive or negative with regard to the same indicator, the difference is the strength of the correlation.

Table 8-3. Summary of the correlations coefficient of transmission power with the selected indicators

	GERD	Number of researchers	GDP growth rate	GDP per capita	HDI	TFP
USA	– 0.26	– 0.69	0.25	– 0.83	– 0.75	– 0.98
Canada	0.78	– 0.56	0.11	– 0.57	– 0.8	–0.31
France	– 0.75	– 0.23	0.68	– 0.15	– 0.61	0.57
Germany	– 0.9	– 0.74	0.54	0.52	– 0.60	–0.13
Japan	0.85	0.4	–0.17	0.91	0.59	0.81
South Korea	0.64	0.66	–0.49	0.73	0.36	0.72

8.5. Discussion

The Triple Helix indicators computed from scientific publications data reveal different patterns of the dynamics of the national innovation systems of the selected countries. Globally, the Japanese national innovation system exhibits the largest synergy, followed by France, USA, Canada, South Korea and Germany.

8.5.1. *Globalization erodes synergy at national level*

The leading position of Japan with regard to the mutual information was already recorded by Leydesdorff (2003) and that of Japan and France by Ye et al. (2013) for the year 2011, while the latter study computed the mutual information of a set of countries including the ones we selected. Our results globally confirm the ranking of countries (Ye et al., 2013) obtained after calculation mutual information based on data from Web of Science, except that Canada and South Korea interchange their ranking. They also conform to the findings that for most countries, the mutual information's absolute value is decreasing (Ye et al., 2013). This trend is due to globalisation that erodes the synergy between national innovation actors (Leydesdorff & Park, 2014; Leydesdorff & Sun, 2009; Ye et al., 2013). Indeed, globalization gives opportunities to research institutions to cooperate widely regardless of the distance separating their home countries; it has enlarged worldwide partnership (Waltman et al. 2011). Therefore, a university in one country has the opportunity to collaborate with a company or a governmental body, each located in different countries. This form of collaboration, even though linking the three innovation actors of the Triple Helix, escapes to be accounted for the synergy at the national level, as the present research paper measures it. Hence, the synergy at the national level diminishes.

Leydesdorff and Sun (2009) located the starting point of globalization after the end of the Cold War between 1990 and 2000; in other words, starting from the demise of the Soviet Union, the unification of Germany, and the opening of China since the early 1990s. The decrease in the absolute value of the mutual information and its small values are therefore a consequence of the internationalization of science in the selected countries (namely Germany, South Korea, Canada and USA). Japan's performance is driven by domestic activity (Adams, King, Miyairi, et al., 2010); this country's national innovation system is less internationalized than that of Canada, the latter is more integrated in the Anglo-American system (Leydesdorff & Sun, 2009). Before globalization, USA had the highest share in the international papers of all countries (Glänzel, 2001, p. 87; Zitt et al., 2000, p. 641); therefore, it should be expected that its mutual information and transmission power show a lower value over the period of study. In the case of South Korea, the gain of synergy, although slow over time, may be interpreted as the consequence of strengthening of its national innovation system after years of benefiting from international collaboration. This situation is a consequence of changes in this country's policies over decades (Kwon et al., 2012).

8.5.2. *Strengthening domestic co-authorship explains the performance of South Korea and Japan*

Table 8-4 and Figure 8-9 show the time series of the entropies of the selected countries innovation systems and the equation of their linear trends. Except for Japan and South Korea, which have an increasing trend, all the remaining countries have a decreasing one. The same trend is registered as regarding the bilateral entropies H_{UI}, H_{UG} and H_{IG} (cf. Table 8-5 to Table 8-7 and Figure 8-10 to Figure 8-12).

The entropy of a system is the quantity of information or knowledge produced within the system. In other words, the quantity of information or knowledge produced by the Japanese and South Korean information systems are growing, whereas in the other countries, it is diminishing. Therefore, it is unsurprising that the share that circulated between actors (the transmission power) at the domestic level also decreases. That explains the negative correlation of the transmission power with the selected indicators in the American and European selected countries.

The expression of H_{UIG} drawn from Equation (8–6) is:

$$\mathrm{H_{UIG}} = \mathrm{H_{UI}} + \mathrm{H_{UG}} + \mathrm{H_{IG}} - \mathrm{H_U} - \mathrm{H_I} - \mathrm{H_G} + \mathrm{T_{UIG}} \tag{8-8}$$

Equation (8–8) shows that H_{UIG} has a positive relation with the bilateral entropies. In order words, the bilateral entropies add to the system entropy, e.g. an increase in the bilateral entropies engenders an increase in the system's entropy. That is the case of Japan and South Korea. Conversely, the four other countries' bilateral entropies have decreased; consequently, the system's entropy decreases. This emphasizes the role of collaboration in knowledge production and sharing for innovation.

The decreasing trend of bilateral entropies in the USA, Canada, France and Germany innovation system should not be interpreted as lack of collaboration between University, Industry and Government; it may have resulted from the an increase in collaboration with partners abroad; we have concluded that international collaboration has eroded the mutual information at domestic level. We should recall that this study doesn't include foreign innovation actors in the computation of the indicators, and that the Japanese co-authorship is domestic and that South Korea has engaged in strengthening its domestic science.

Table 8-4. Trilateral entropies (in millibits of information) of the selected countries' innovation system

Year	USA	Canada	France	Germany	Japan	Korea
2001	729.851	819.975	1,190.616	638.752	1,424.249	526.043
2002	754.738	819.719	1,211.682	653.975	1,457.269	547.451
2003	741.297	807.656	1,228.321	658.823	1,447.158	587.428
2004	726.235	815.338	1,222.301	657.701	1,475.7	606.483
2005	718.794	805.235	1,222.675	654	1,469.972	594.532
2006	705.919	800.221	1,188.216	660.75	1,478.722	589.696
2007	703.591	787.627	1,181.216	671.309	1,471.127	606.704
2008	693.485	760.854	1,137.709	631.379	1,514.607	615.654
2009	668.871	758.015	1,087.766	624.111	1,490.306	606.096
2010	656.345	751.627	1,098.313	630.187	1,490.864	615.483
Linear trend	$y = -9.59t + 762.66$	$y = -8.30t + 838.27$	$y = -14t + 1253.8$	$y = -2.28t + 660.62$	$y = 7.05t + 1433.2$	$y = 8.20t + 544.48$

Note: $t = 1$ in 2001

Table 8-5. Bilateral UI entropies (in millibits) of the selected countries' innovation system

Year	USA	Canada	France	Germany	Japan	Korea
2001	559.474	735.159	1,091.272	607.27	1,143.375	491.671
2002	565.536	729.738	1,110.999	618.58	1,152.715	503.738
2003	559.894	714.402	1,124.475	619.61	1,141.474	536.411
2004	540.956	720.963	1,117.249	616.683	1,144.324	535.858
2005	526.745	709.851	1,113.492	610.809	1,143.262	531.304
2006	512.24	705.148	1,070.496	611.067	1,145.632	522.726
2007	508.441	695.614	1,063.908	625.651	1,148.147	536.084
2008	494.892	665.913	1,020.863	597.43	1,176.828	538.503
2009	471.413	664.764	977.762	599.92	1,149.824	522.646
2010	450.683	649.241	976.235	605.648	1,131.494	527.552
Linear trend	-12.58 t + 588.20 R2 = 0.95	-9.4t + 750.8 R^2 = 0.93	-16.3 + 1156.3 R^2 = 0.76	-1.39t + 618.9 R^2 = 0.22	0,38t + 1145.6 R^2 = 0.01	2.77t + 509.39 R^2 = 0.29

Note: t = 1 in 2001

Table 8-6. Bilateral UG entropies (in millibits) of the selected countries' innovation system

Year	USA	Canada	France	Germany	Japan	Korea
2001	559.599	468.528	866.542	426.113	946.201	262.233
2002	587.161	460.11	879.795	433.926	964.487	270.061
2003	574.624	459.258	882.365	440.406	956.054	299.824
2004	560.139	452.519	864.658	441.444	967.815	310.81
2005	556.661	439.249	863.347	432.814	951.704	313.28
2006	542.024	433.281	826.216	431.688	962.854	315.409
2007	539.658	410.56	786.794	432.371	947.244	329.624
2008	530.672	398.942	727.657	388.402	977.248	326.694
2009	509.272	389.703	671.407	371.095	965.444	316.782
2010	495.185	372.874	663.921	373.06	958.85	312.774
Linear trend	-8.61t + 592.86 R^2 = 0.85	-10.83t + 488.07 R^2 = 0.96	-26.22t + 947.49 R^2 = 0.85	-7.31t + 457.32 R^2 = 0,63	1.07t + 953.93 R^2 = 0.11	5.91x + 273.25 R^2 = 0.63

Note: t = 1 in 2001

Table 8-7. Bilateral IG entropies (in millibits) of the selected countries' innovation system

Year	USA	Canada	France	Germany	Japan	Korea
2001	621.857	692.899	986.677	538.279	1153.541	450.415
2002	640.732	692.878	1001.537	549.48	1180.139	468.975
2003	630.732	682.566	1011.154	554.031	1174.243	505.709
2004	618.067	690.249	1002.236	553.779	1198.665	521.459
2005	611.38	682.913	1002.34	549.932	1196.614	511.233
2006	601.073	676.984	975.202	554.646	1203.051	506.911
2007	599.174	669.151	963.293	562.195	1197.356	521.682
2008	590.898	647.687	928.323	527.304	1231.088	532.322
2009	571.291	644.932	887.773	519.219	1212.968	526.393
2010	561.979	642.713	897.239	524.017	1218.003	539.484
Linear trend	-7.83t + 647.76 R^2 = 0.90	-6.25t + 706.66 R^2 = 0.88	-13.99t + 1,253.8 R^2 = 0.75	-2,69t + 558.08 R^2 = 0.30	6.65t + 1160 R^2 = 0.79	8.08t + 464.03 R^2 = 0.75

Note: t = 1 in 2001

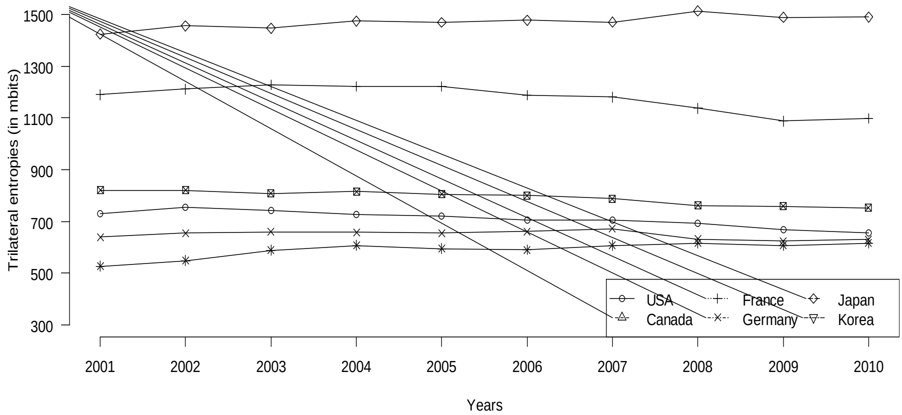


Figure 8-9 Trilateral entropies (in millibits) of the selected countries

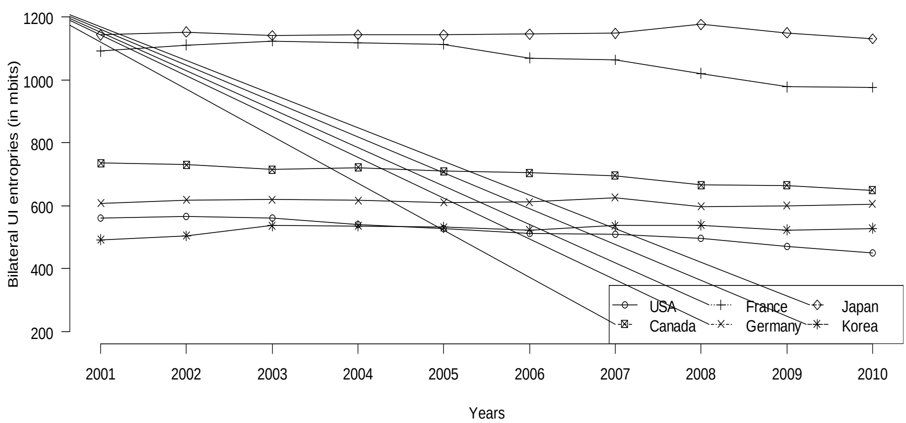


Figure 8-10 BIlateral UI entropies (in millibits) of the selected countries

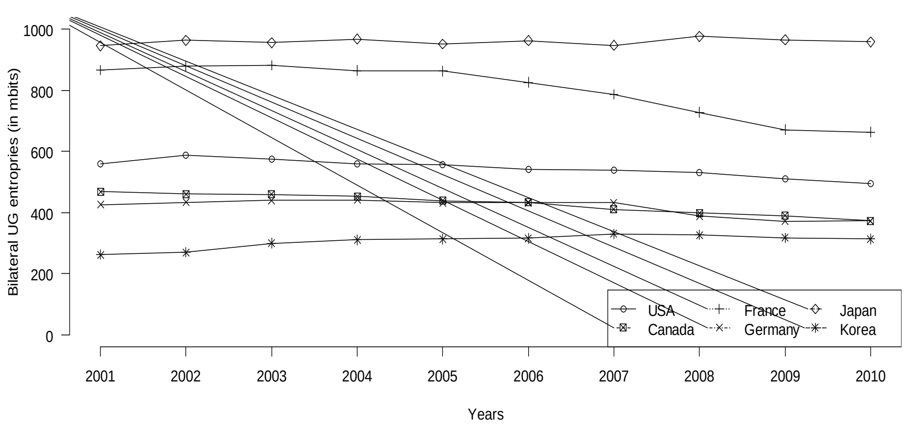


Figure 8-11 BIlateral UG entropies (in millibits) of the selected countries

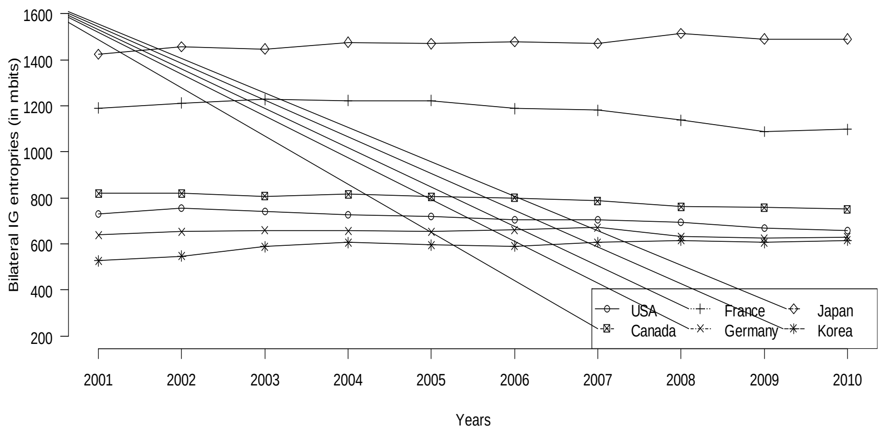


Figure 8-12 Bilateral IG entropies (in millibits) of the selected countries

8.5.3. Investment in R & D feeds synergy at national level

The GERD as percentage of the GDP of the countries over the period of study (Figure 8-13) and the number of researchers per thousand inhabitants (Figure 8-14) shed more light on the gain of synergy within the South Korean innovation system. Indeed, at the beginning of the period, South Korea's GERD is equal to 2.59 and South Korea was ranked third, after Japan and USA; it rises to 3.06 in 2006 and reaches 3.56 in 2009 making South Korea the country with the highest GERD as percentage of GDP within the set of the six selected countries starting from 2009. The same trend is recorded for the number of researchers per thousand inhabitants. This steady investment in research and development may have strengthened collaboration between innovation actors at national level. It explains the performance of the country with regard to mutual information and transmission power; it illustrates the efforts South Korea has made to catch up with leading economies (OECD, 2009, p. 13). We should underline that Japan and South Korea has the highest GERD as percentage of GDP meaning that these two countries have been investing heavily in research and development, and hence, in human capital. If Japan has this tradition (its GERD equalled 2.9% GDP in 1990 and has reached 3% since 2000, cf. data in (OECD, 2014a), South Korea has prioritized strengthening its economy towards a developed one (Kwon et al., 2012; OECD, 2009).

These results illustrate that investing in research and development (e.g. GERD and research personnel) strengthens the innovation system research and extends research collaboration. Therefore, opportunities for doing research and research collaboration between innovation actors are widened; knowledge could then be created and shared by and among innovation actors at national level. Indeed at the origin, the mutual information, borrowed from the Shannon's (1948) information theory, indicates the quantity of information common to two variables. In case of more than two variables (the three actors of an innovation system, in our case), it measures the synergy within the system if it is negative, or the control one actor exerts on the others if it is positive (Leydesdorff, 2003). The transmission power is the normalization of the mutual information; it is obtained by dividing the mutual information by the maximum value it may reach according to the variables value (Mêgnigbêto, 2014a); it can be interpreted as the efficiency of the mutual information. In other words, the transmission power is the fraction of the quantity of the 'sharable information' that is actually shared within the system. It indicates the extent to which the produced information and knowledge flow between innovations actors (Mêgnigbêto, 2014b, 2014c).

8.5.4. South Korea has gained profit more than other countries

Figure 8-15 plots the TFP (base = 100 in 2005) of the selected countries. It shows that before 2005, the South Korean TFP was the lowest but has become the highest after with a significant gap. The OECD states that, TFP is the part of GDP growth that cannot be explained by changes in labour and capital inputs. According to the World Bank (World Bank, 1999, p. 19 Table 1.2), at least 70% of growth rate is explained by intangible factors like knowledge, not by labour and capital. Indeed, the other countries have attained a certain level of development; a country like South Korea which 'suddenly" starts investing should have a shift in its output. That is why even though South Korea's GERD equals that of Japan only in 2007 and its numbers of researchers that of Japan only in 2009, the TFP (base = 100 in 2005) has risen. In conclusion the investment in R & D by South Korea since early 2000 as the results of changes in the country's research and innovation policy may have influenced the TFP time series.

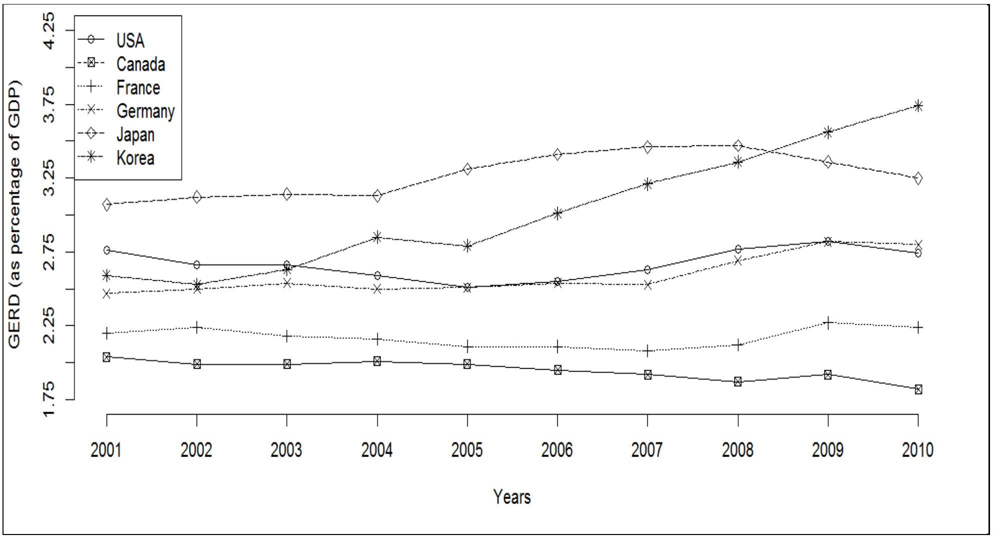


Figure 8-13 GERD of the selected countries.
Source: OECD (2014a)

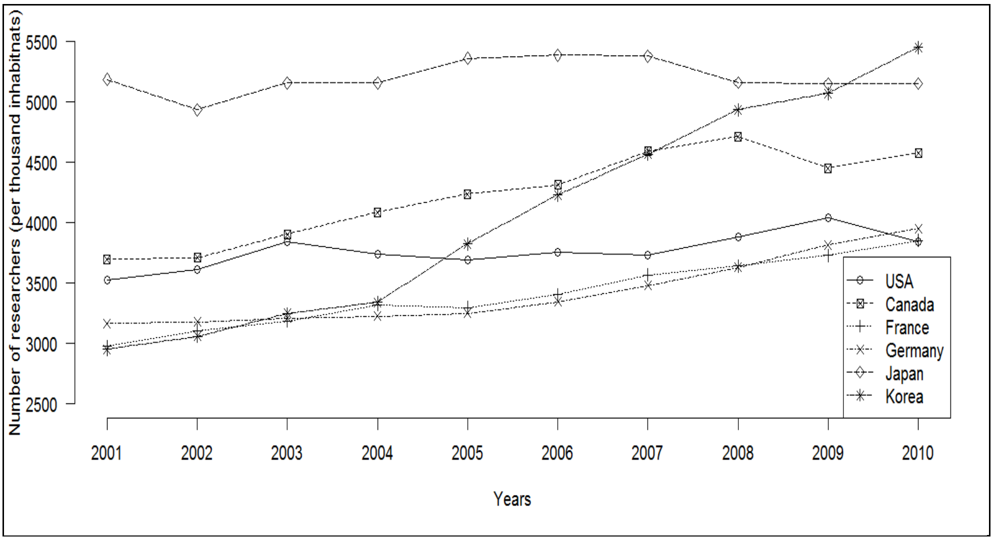


Figure 8-14 Number of researchers per thousand inhabitants of the selected countries.
Source: OECD (2014b)

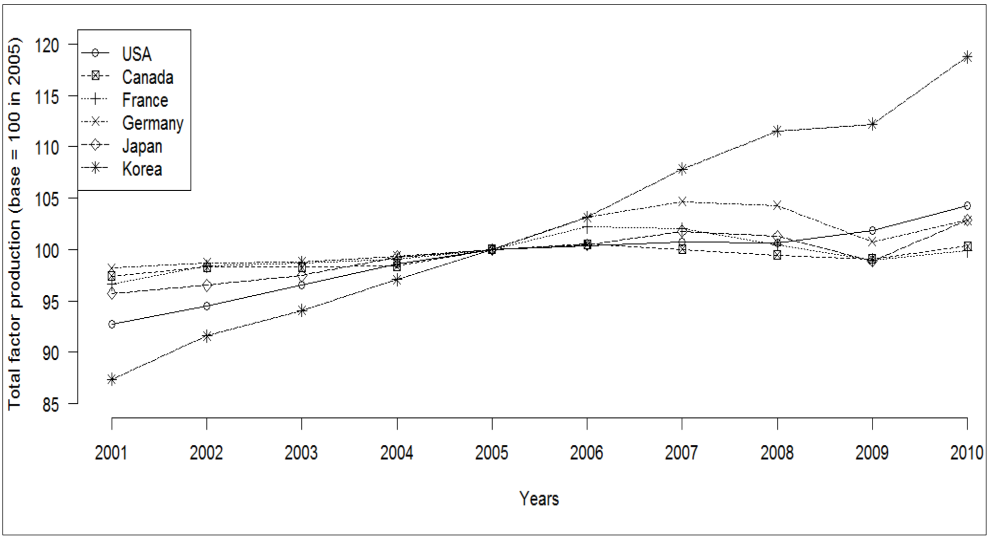


Figure 8-15 Multifactor productivity of the selected countries.
Source: OECD (2015b)

8.6. Conclusion

This chapter aimed to study the correlation between the transmission power and some selected indicators used to measure the knowledge-based economy, taking the case of six OECD countries namely USA, Canada, France, Germany, Japan and South Korea. The results show that the selected countries don't have the same pattern with regard to the selected indicators. Indeed, while some countries exhibit a positive correlation regarding the transmission power and a particular indicator, others show a negative correlation between the transmission power and the same indicator. However, Japan and South Korea exhibit a positive strong correlation between the transmission power and GERD on the one hand and the transmission power and the number of researchers on the other hand; they also have the same pattern as regarding the correlations studied. The particular situation of these two countries is due to the domestication in co-authorship in the Japanese science and the efforts of strengthening the national innovation system at the South Korean level. On the opposite, the four remaining countries are affected by the international collaboration they are involved in.

The results did not allow drawing any evident relation between the transmission power and the selected indicators, certainly because the transmission power captures a dynamic that is missing from other indicators. However, the study showed that the transmission power as measured by the method used informs only at the country level and does not measure the added value University, Industry and Government relationships create at the international level. Therefore, reasonably it could not be used for absolute comparison of countries unless the synergy created abroad is taken into account with the inclusion of University-Industry-Government relationships at international level. This study shows that investments in research and development, particularly a constant increase in GERD and research personnel or equipment, strengthens domestic collaboration and give more opportunity for knowledge sharing at the country level. There is however a need for innovation system actors both to favour collaboration between innovation actors at the domestic level and enlarging collaboration at the international level in order to contribute to knowledge sharing abroad.

From this study, we could conclude that if collaboration sustains innovation and contributes to economic growth, mutual information and transmission power may be means for measuring the advances attained.

9. International collaboration and knowledge flow within an innovation system

This chapter computes the effect of international collaboration on the synergy and knowledge circulation within an innovation system. Three levels of study are considered: the domestic one, the foreign one and the global. The mutual information and the transmission power are used as indicators, West African region and South Korea served as cases of studies.

This chapter is based on a conference paper presented at the V^{ème} Colloque de l'Université d'Abomey-Calavi (Mêgnigbêto, 2015b) and an article published in the Triple Helix Journal (Mêgnigbêto, 2015a).

9.1. Introduction

Two types of models of innovation were proposed up to now to explain the functioning of an economy: the linear and the nonlinear models. Each explains how growth is generated. The linear model postulated that "innovation starts with basic research, is followed by applied research and development, and ends with production and diffusion" (Godin, 2005, 2006b, 2014). The nonlinear model introduced with the national innovation system concept "suggests that the research system's ultimate goal is innovation and that the system is a part of a larger system composed of sectors like Government, University and Industry and their environment. The system also emphasized the relations between the components or sectors as the "cause" explaining the performance of innovation system" (Godin, 2007, p. 5). Both models have been criticized (Godin, 2005, 2006b, 2007) and variants of them were proposed. In the national innovation system model, analysis focuses on the flows of knowledge between actors (OECD, 1997, p. 11).

The Triple Helix laid down by Etzkowitz and Leydesdorff (1995, 2000, p. 2) is one of the variants of the nonlinear model of innovation (cf. Etzkowitz & Leydesdorff, 2000; Leydesdorff, 2012b, p. 26; Meyer et al., 2014, p. 153). The model postulates that the interactions between University, Industry and Government maintain a knowledge infrastructure that generates knowledge of which circulation among innovation actors drives economic growth and social welfare (Leydesdorff & Etzkowitz, 2001). The mutual information (Leydesdorff, 2003) was elaborated as an indicator of the Triple Helix relationships between University, Industry and Government. It has been used widely to assess countries or region profiles (e.g. Khan & Park, 2011; Leydesdorff et al., 2013; Leydesdorff & Sun, 2009; Mêgnigbêto, under review, 2013g, 2015; Shin et al., 2012) or assess the knowledge base of economies (Leydesdorff et al., 2015; Leydesdorff & Zhou, 2013; Park et al., 2005). The transmission power was proposed by Mêgnigbêto (2014a) as the normalization of the mutual information. It was used to assess the knowledge flow within the West African innovation systems, both at national and regional levels (Mêgnigbêto, 2014b, 2014c); it was also used to compare the knowledge production profiles of six OECD countries (Mêgnigbêto, under review, 2015c). Jointly with other indicators, it helped in studying the Norwegian innovation system both at national and county level, based on data including the number of establishments in geographical, organizational, and technological dimensions over a 13-year period (Ivanova et al., 2014).

The Triple Helix model relies on collaboration. When publications serve as unit of analysis, co-authorship is taken as a measurement of collaboration (Abbassi et al., 2012; Bordons & Gomez, 2000; Katz & Martin, 1997; Olmeda-Gómez et al., 2008); indeed, it entails the tacit transfer of information and knowledge (Olmeda-Gómez et al., 2008) and ensures diffusion of ideas and knowledge circulation (Guns & Rousseau, 2014). The importance of co-authorship in knowledge creation and sharing may be measured by the international co-authorship trend. Indeed, publications on co-authorship worldwide all reported an increasing trend in the number of authors who contributed to an article (e.g. Adams, 2012; Adams et al., 2014; Adams et al., 2010; Bordons & Gomez, 2000; Boshoff, 2009; Leydesdorff et al., 2013; Leydesdorff & Wagner, 2008; Mêgnigbêto, 2013a; Onyancha & Maluleka, 2011b; Ossenblok et al., 2014; Tijssen, 2007; Toivanen & Ponomariov, 2011; Wagner et al., 2015). Some of them underlined the concentration of the growth in the group of papers with five or more authors, underlining the strong importance of co-authorship in scientific publishing. As an illustration, research collaboration networks have been evolving and countries that were at the periphery are becoming member of the core; besides, the global international collaboration network has become denser (Leydesdorff & Wagner, 2008). Globally, co-authorship has exploded recently (Adams, 2012) and internationalisation of collaboration characterizes science today (Adams, 2013) due mainly to globalization[69]. Therefore, by the means of collaboration, innovation actors contributed to synergy and knowledge creation both at national and international levels. Leydesdorff and Zawdie (2010) affirmed that "knowledge-based economy develops as a dynamic system at the global level, thus transcending national or geographical boundaries".

At our knowledge, few papers studied international co-authorship in relation with the Triple Helix. Firstly, Leydesdorff and Sun (2009), Kwon (2011) and Kwon et al. (2012) included the internationally co-authored papers as a fourth element of the model; this method requires a huge amount of data processing and cleaning of the institutional address information (Leydesdorff & Sun, 2009, p. 215). Secondly, Choi et al. (2015) studied the intra-sectors co-authorship at international level. And thirdly, Shin et al. (2012) combined domestic and international collaboration by University, Industry, and Government and their bi or trilateral output.

[69] According to UNESCO (2010a), "globalisation is the ongoing process that is linking people, neighbourhoods, cities, regions and countries much more closely together than they have ever been before. The process is driven economically by international financial flows and trade, technologically by information technology and mass media entertainment, and very significantly, also by very human means such as cultural exchanges, migration and international tourism". So this definition includes economic, technological, and cultural aspects of the phenomena.

The above mentioned studies computed neither the synergy or knowledge the national innovation actors contributed abroad nor its effect on the synergy or knowledge creation and sharing at national level; therefore, they could not measure the real amount of knowledge that circulates among an area' s innovation actors (Mêgnigbêto, under review, 2015c). Indeed, globalization has given opportunities to researchers to collaborate worldwide regardless the distance (Waltman et al., 2011). Besides, it has eroded some countries' mutual information (Kwon et al., 2012; Leydesdorff & Park, 2014; Leydesdorff & Sun, 2009), and might have affected how knowledge is shared at the country's level.

Because the mutual information at a country's level could have been eroded by international co-authorship, it is not sufficient alone to indicate how knowledge-based an economy is (Mêgnigbêto, under review, 2015c). So, while comparing countries on the basis of the mutual information or derived indicators, the synergy contributed due to international collaboration remains unilluminated. Thus, the comparison may be biased. As an example, the Japanese research performance is driven by domestic activity (Adams, King, Miyairi, et al., 2010). This country's mutual information was always higher while compared to that of other countries (Leydesdorff, 2003; Mêgnigbêto, 2014a, 2015c; Park et al., 2005; Ye et al., 2013). The conclusion that the synergy at the Japanese national level is higher than elsewhere is true but deriving that the Japanese economy is more knowledge-based than that of another country may not be.

In this chapter, we hypothesize that the synergy or knowledge contributed at the international level by a country's domestic innovation actors may have affected the synergy or knowledge they created at the national level. In other words, foreign innovation actors can influence the synergy and knowledge creation and sharing at a country's level. Our research question is twofold: i) How to measure the synergy or knowledge contributed to abroad by an area's innovation actors due to their relations with their foreign partners? ii) What is the effect of international collaboration on knowledge flow within an innovation system?

9.2. Methods

9.2.1. Mutual information and transmission power

The mutual information is borrowed from the Shannon's (1948) information theory. Central to this theory is the notion of entropy defined as the average quantity of information contained is a variable. Shannon (1948) defined the entropy of an event that occurs with the probability p as:

$$\mathrm{H} = -\mathrm{p} \times \log_2 \mathrm{p} - (1-\mathrm{p}) \times \log_2 (1-\mathrm{p}) \tag{9-1}$$

where log2 is the logarithm to the base 2; the entropy may however be computed to other bases e.g. 3, 4, ..., 10). More generally, if $\mathrm{X} = (\mathrm{x}_1, \mathrm{x}_2, \dots, \mathrm{x}_\mathrm{n})$ is a random variable and its components occur with the probabilities $p_1, p_2, \dots, p_n$ respectively, then the entropy generated by X is (cf. Shannon, 1948; Shannon & Weaver, 1949)

$$H_X = -\sum_{i=1}^{n} p_i \times \log_2 p_i \quad (9\text{-}2)$$

For two random variables X and Y, if H_X is the entropy of X and H_Y that of Y, the joint entropy H_{XY} of the system of the two variables is equal to the entropy H_X plus H_Y minus the entropy of the overlay of X and Y. The latter is called "rate of transmission" (Shannon, 1948) or mutual information (Cover & Thomas, 2006; Leydesdorff, 2003, 2008; Mori, 2006; Yeung, 2001, 2008) between X and Y. The relations between the transmission, T_{XY}, the joint entropy H_{XY} and the marginal entropies of the variables, H_X and $H_{Y,}$ are (1948):

$$H_{XY} = H_X + H_Y - T_{XY} \quad (9\text{-}3)$$

and

$$T_{XY} = H_X + H_Y - H_{XY} \quad (9\text{-}4)$$

In case of three random variables X, Y and Z (three dimensions), the relations between the system's entropy, its transmission, the marginal entropies and the bilateral transmissions are given by (cf. Abramson, 1963; Leydesdorff, 2003; Theil, 1972):

$$H_{XYZ} = H_X + H_Y + H_Z - T_{XY} - T_{XZ} - T_{YZ} + T_{XYZ} \quad (9\text{-}5)$$

and

$$T_{XYZ} = H_X + H_Y + H_Z - H_{XY} - H_{YZ} - H_{XZ} + H_{XYZ} \quad (9\text{-}6)$$

The transmission power of a system is the fraction of the maximum value of the transmission devoted to information sharing in the system; it represents the share of the "total configurational information" really produced in the system. In other words, it measures the efficiency of the mutual information.

For a three-dimensional system, Mêgnigbêto (2014a) distinguished two types of transmission power: the first one (τ_1) when the transmission is negative, and the second (τ_2) when the transmission is positive:

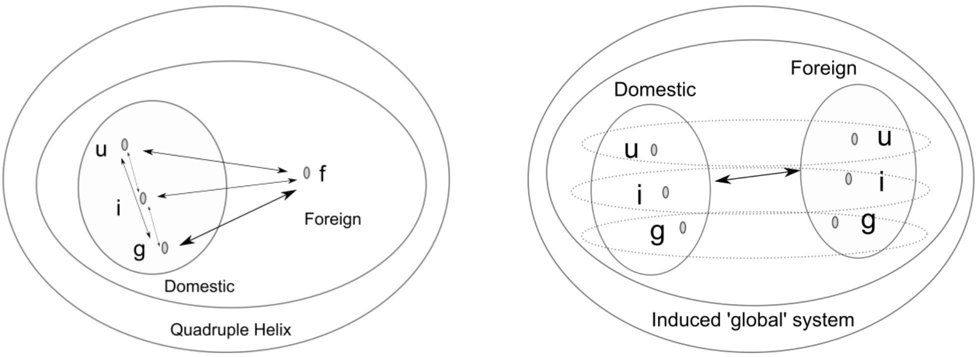
$$\tau = \begin{cases} \tau_1 = \frac{T_{XYZ}}{H_{XYZ} - H_X - H_Y - H_Z} \text{ if} T_{XYZ} < 0 \\ \tau_2 = \frac{T_{XYZ}}{H_{XYZ}} \text{ if} T_{XYZ} > 0 \\ 0 \text{ if} T_{XYZ} = 0 \end{cases} \quad (9\text{-}7)$$

The transmission power varies from 0 to 1; it is dimensionless and may be expressed as a percentage (Mêgnigbêto, 2014a).

9.2.2. Domestic, foreign and global systems

Leydesdorff and Sun (2009), Kwon (2011) and Kwon et al. (2012) named 'foreign' institutions from partner countries and considered it as the fourth element of the innovation system composed with the three national actors that are University (u), Industry (i) and Government (g), leading to the computation of the mutual information (T_{uigf}) of the Quadruple Helix. The type of the institutions involved was not taken into account; Figure 9-1-a illustrates this method. Our method suggests considering three levels of analysis: i) the domestic one grouping the country or area-based innovation actors as done in the literature hitherto, ii) the foreign one grouping the innovation actors from the partner countries, and, iii) the global grouping the two previously defined systems Hence, the global system may be considered as composed with the 'domestic' and the 'foreign' sub-systems, each with three innovation actors leading to six actors at the global level (Figure 9-1-b). The two sub-systems interact and exert on each other a mutual influence that may act on the synergy within each other by the mutual relationships they entertain. The relationships existing between the actors on Figure 9-1-a (as represented by arrows) also exist within the domestic sub-system on the one hand, and the foreign one on the other hand (Figure 9-1-b). Abstraction is done of these relationships on Figure 9-1-b however. Studying such a Sextuple Helix (Leydesdorff, 2012) requires the computation of 2^6 = 64 sectors data.[70] A simpler way to proceed consists in considering the global system as if actors were from the same geographical area and studying separately the three domestic, foreign and global Triple Helix systems. Thus, we can compute the mutual information and transmission power of the domestic, foreign and the global systems using the formulas given above. We suggest using the normalised difference between the global and domestic transmission power as the effect of international collaboration on knowledge flow within an innovation system.

[70] If the number of variables is n, the system may be decomposed into 2^n subsets (cf. Mêgnigbêto, 2014, pp. 285–286).



(a) Method used by Leydesdorff and Sun (2009), Kwon (2011) and Kwon et al. (2012)

(b) Method proposed in this study

Figure 9-1 Illustration of the methods for integrating foreign actors to the computation of the Triple Helix indicators.

Note: Sectors are represented by small circles meaning the intra-sectorial relations (loops).

9.2.3. International collaboration and transmission power

Because a record could have both foreign and domestic co-authors, the method of entropy decomposition suggested by Theil (1972, pp. 20–23) is not applicable; indeed, the number of records from 'domestic' and that from 'foreign' do not sum up to the number of records at the global level. We suggest computing the mutual information and transmission power of the domestic, foreign and the global systems using the formulas given above. Hence, it seems that Shin et al. (2012) computed the domestic and global mutual informations for Saudi Arabia without using these denominations, but they did not compute the foreign mutual information; they did not compute the transmission power values any longer.

If we denote τ_d, the domestic transmission power, τ_f the foreign one and τ_g the global one, the effect of the international collaboration on an area may be measured with the scalar $\frac{\tau_g - \tau_d}{\tau_d}$ expressed as percentage. We argue that the total knowledge within such a system is measured by τ_g. Therefore, one can compute the total transmission power for such a country and compare countries on this basis. In this section, we do not consider the knowledge created at the foreign level solely because it does not add any value to our interpretation and its effects combined with the domestic included in the global values. However, it may help in assessing the level of integration on the innovation system at the country level.

9.2.4. *Data collection*

The data source is the Web of Science. Our research question requires the distinction between the papers originated from an geographic area's University, Industry and Government relationships and those resulting from the collaboration with at least one University, Industry or Government abroad. If the Web of Science search language could permit to retrieve the first category of papers, the second category is not searchable with it. Therefore, we opted for data downloading for further relevant treatment.

The primary area for the application is the West African region; however, Korea, a country which some decades ago had the same economic and social conditions as the West African countries, has been steadily studied with regard to Triple Helix dynamics (e.g. Khan & Park, 2011; Mêgnigbêto, under review, 2015c; Park et al., 2005; Park & Leydesdorff, 2010); therefore, it is chosen for comparison purpose. So, this article treats the scientific data of the West African region and South Korea. West African[71] and South Korean[72] publications data from Web of Science[73] over a ten-year period (2001-2010) were downloaded. This article treats the scientific data of the West African region and South Korea. The records resulting from these two searches were imported into two different bibliographic databases, with the same structure, managed with the CDS/ISIS software application.

9.2.5. *Data treatment*

Based on Leydesdorff (2003, p. 458) and Park et al.'s (2005, p. 13 ff.) method for address assignment, a list of words or abbreviations were established to attribute each record address a label: UNIV for University, INDU for Industry or GOV for Government. A second CDS/ISIS Pascal programme was coded for this task. A record may contain many addresses; therefore, one record may have two or more different labels. The CDS/ISIS Pascal programmes were also instructed to read the countries' name from the addresses and automatically add the associated area name: West-Africa for the West African database and Korea to the South Korean database. Addresses that do not relate to any West African country or South Korea are labelled 'FOREIGN'. So, in the inverted file of the databases, a university in West Africa appears under the label UNIV-WEST-AFRICA, an enterprise in South Korea appears

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[71] The search expression was (cu=benin or cu=Burkina faso or cu=cote ivoire or cu=cape verde or cu=gambia or cu=ghana or cu=guinea or cu=guinea bissau or cu=liberia or cu=mali or cu=niger or cu=nigeria or cu=senegal or cu=sierra leone or cu=togo) and (py=2001-2010). It also selected data of countries like Equatorial Guinea and Papua New Guinea due to the term guinea. The records of these two countries that not resulted from collaboration with any West African countries were deleted from our local database.
[72] The search expression was cu=south korea and py=2001-2005.
[73] The databases searched were Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index-Science (CPCI-S), Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH).

under the label INDU-KOREA, and a foreign university (from the West Africa or South Korean point of view) under UNIV-FOREIGN, etc. As a result, the inverted file contains only the following keywords, in the alphabetic order:[74] GOV-FOREIGN, GOV-KOREA, INDU-FOREIGN, INDU-KOREA, UNIV-FOREIGN, UNIV-KOREA for the South Korean data and, GOV-FOREIGN, GOV-WEST-AFRICA, INDU-FOREIGN, INDU-WEST-AFRICA, UNIV-FOREIGN, UNIV- WEST-AFRICA for the West African data.

The CDS/ISIS search functions were used to compute the University, Industry and Government outputs and their bi or tri lateral collaboration data at the domestic, foreign and global levels. The CDS/ISIS search function operates mainly over the inverted file that contains "searchable terms" as initially defined by the database administrator into a file called Field Selection Table (UNESCO, 1989a, p. 75). It admits the Boolean operators OR symbolized by the sign + (plus), AND symbolized by the character * (star) and NOT symbolized by the character ^ (circumflex). It also admits free search expression and parentheses to prioritize part of a search expression and hashtag (#) to recall a previous search by its number (UNESCO, 1989a, pp. 97–105). The following searches summarize the search strategy adopted (the example is based on the South Korean case and is related to the computation of the domestic level data (See Appendix 11):

#1: UNIV-KOREA selects all records with at least one South Korean-based university in affiliation;

#2: INDU-KOREA selects all records with at least one South Korean-based industry in affiliation;

#3: GOV-KOREA selects all records with at least one South Korean-based government in affiliation;

#4: #1 * #2 selects all records with at least one South Korean-based university AND one South Korean-based industry in affiliation;

#5: #1 * #3 selects all records with at least one South Korean-based university AND one South Korean-based government in affiliation;

#6: #2 * #3 selects all records with at least one South Korean-based industry AND one South Korean-based government in affiliation;

#7: #1 * #2 * #3 selects all records with at least one South Korean-based university AND one South Korean-based industry AND one South Korean-based government in affiliation.

The print service of CDS/ISIS was used to output the publication year of the searches results into text files for statistical analyses with the R software (R Development Core Team, 2014) ; then, the repartition of records per year of publication were obtained. The results of each stage were entered into a worksheet; and on a second worksheet,

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[74] Not categorized addresses were labelled 'NC'; so the inverted file also contained NC-WEST AFRICA, NC-FOREIGN for the West African database and NC-KOREA, NC-FOREIGN for the Korean database.

formulas are entered to compute University, Industry and Government sectorial output and other bilateral and trilateral collaboration data using the formulas,[75] following the logical relation between sets in Figure 9-2:

i) U = [1] – [4] – [5] + [7],
ii) I = [2] – [4] – [6] + [7],
iii) G = [3] – [5] – [6] + [7],
iv) UI = [4] – [7],
v) UG = [5] – [7],
vi) IG = [6] – [7],
vii) UIG = [7].

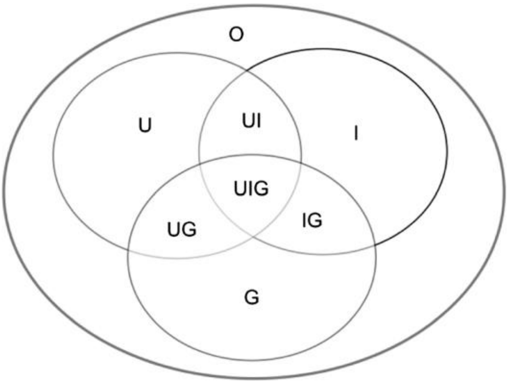


Figure 9-2 Cardinalities in a tri-dimensional system S = (U, I, G).

This strategy was executed for each area at the three levels (domestic, foreign and global). Appendix 11 illustrates the case of South Korea. We coded a PHP programme that computes the sectorial entropies, the bilateral entropies and mutual informations, and the trilateral entropies and mutual information and the transmission powers according to the formulas given above. All the levels of analysis (domestic, foreign and global) were taken into account.

9.3. Results

9.3.1. Output and international collaboration

Table 9-1 and Table 9-2 provide basic data respectively on the West African and the South Korean scientific publishing over the considered period of times: output, number of co-authors, average number of co-authors per paper, number and percentage of papers resulting from international collaboration. Over the decade, South Korea outputs a total of 368,729 papers and West Africa 30,717 papers; this leads to an annual average of 38,873 papers for South Korea and 3,072 for West

[75] In these formula the square brackets symbolises the number of records resulting from the search.

Africa. One South Korean publication out of five has at least one foreign co-author and about half of West African publications have at least one foreign co-author. For both areas, the number of papers with at least one foreign address is increasing in absolute value; however, the trend seems to decrease very slowly in percentage. South Korea foreign co-authorship is more or less stable compared to West Africa. Both outputs increase with a linear trend (Figure 9-3 and Figure 9-4). The number of co-authors per paper rose progressively from 2.39 in 2001 to 3.02 in 2010 in the case of West Africa and from 2.09 in 2001 to 2.65 in 2010 in the case of South Korea.

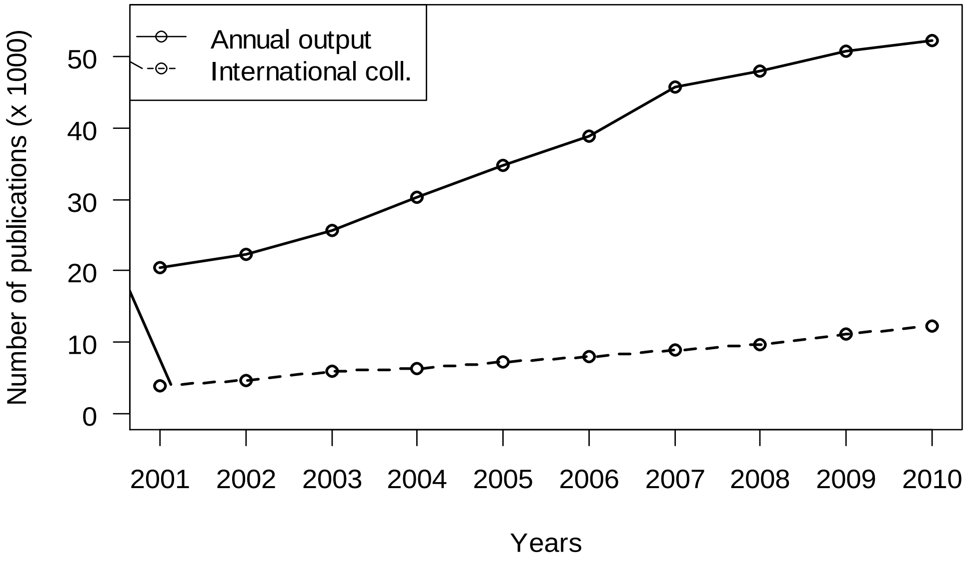


Figure 9-3 Annual output and international collaboration in the South Korean science

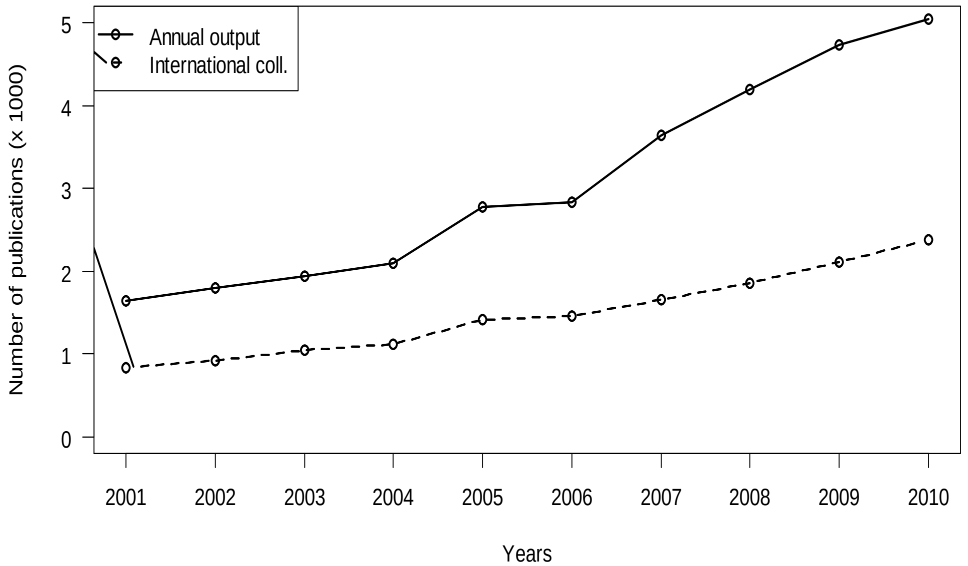


Figure 9-4 Annual output and international collaboration in the West African science

9.3.2. Triple Helix sectorial outputs

The University (U), Industry (I) and Government (G) and their bi or tri-lateral collaborations (UI, UG, IG and UIG) outputs are presented in Table 9-3, Table 9-4 and Table 9-5 with regard to the level of production (e.g. domestic (d), foreign (f) and global (g)). These tables illustrate the problematic of the study: for example, the line labelled 2001 (cf. Table 9-3) indicates that for the West African region, U produces 829 publications at the domestic level, 376 publications at the foreign level and 816 publications at the global one. A closer analysis reveals that 829 − 819 = 10 publications attributed to U at the domestic level do no longer belong to this sector at the global level. In fact, they were co-authored with other innovation actors (I or G) from 'foreign'; so, they accounted for the collaboration of U (UI, UG or UIG) at the global level. For both areas, whatever the sectorial output, the domestic value is higher than the global one for the Triple Helix actors, but lower for their bi or trilateral combinations (See Figure 9-5 to Figure 9-8). This result meant that for both South Korea and West Africa, the international collaboration has strengthened the Triple Helix inter-sectorial collaboration. At the country level, University constitutes an exception in Burkina Faso, Cape Verde, Gambia and Liberia (cf. Table 9-5).

Table 9-1. Total annual output and international collaboration data in the scientific publishing of West Africa

Indicator	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Annual output	1,646	1,796	1,945	2,097	2,779	2,835	3,642	4,198	4,735	5,044	30,717
(Co-)authors	3,932	4,372	4,998	5,588	7,233	7,927	9,916	11,745	13,080	15,215	84,006
Authors per paper	2.39	2.43	2.57	2.66	2.60	2.80	2.72	2.80	2.76	3.02	2.74
International coll.	863	927	1,045	1,123	1,421	1,464	1,655	1,849	2,108	2,386	14,814
International coll. (%)	50.79	51.61	53.73	53.55	51.13	51.64	45.44	44.04	44.52	47.30	48.23

Table 9-2. Total annual output and international collaboration data in the scientific publishing of South Korea

Indicator	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
Annual output	20,512	22,369	25,559	30,283	34,661	38,817	45,740	47,854	50,677	52,257	368,729
(Co-)Authors	42,978	51,482	59,110	69,505	83,178	92,338	107,751	113,352	129,160	138,614	887,468
Authors per paper	2.10	2.30	2.31	2.30	2.40	2.38	2.36	2.37	2.55	2.65	2.41
International coll.	3,918	4,705	5,696	6334	7,271	8,005	8,857	9,685	11,142	12,243	77,856
International coll. (%)	19.10	21.03	23.21	20.92	20,98	20.62	19.36	20.24	21.99	23.42	21.11

Table 9-3. Triple Helix sectorial outputs in West Africa

	U			I			G		
	d	f	g	d	f	g	g	F	g
2001	829	376	819	4	1	4	471	161	321
2002	94	395	896	7	5	6	474	189	307
2003	1,002	471	971	10	6	6	509	180	310
2004	1,149	525	1,112	4	4	2	491	184	297
2005	1,525	653	1,450	6	6	4	673	294	421
2006	1,594	700	1,547	6	2	4	667	235	393
2007	2,198	805	2,058	9	6	9	750	285	439
2008	2,632	928	2,497	11	5	7	783	272	437
2009	3,055	1056	2,887	10	6	7	788	308	434
2010	3,053	1160	2,825	12	10	5	999	377	563
Total	17,977	7069	17,062	79	51	54	6,605	2,485	3,922

Table 9-3 (continuous). Triple Helix sectorial outputs in West Africa

	UI			UG			IG			UIG		
	d	f	g	d	f	G	d	f	g	D	f	g
2001	1	1	2	112	146	387	1	0	2	0	4	4
2002	0	3	3	134	185	458	1	0	2	0	2	6
2003	3	2	8	162	212	526	1	2	4	0	6	10
2004	2	2	9	163	237	562	0	2	2	0	2	3
2005	3	2	8	272	272	774	1	1	3	0	2	q5
2006	6	3	11	253	324	763	0	6	4	2	5	11
2007	8	3	12	351	350	964	1	6	6	0	6	12
2008	13	8	25	426	407	1,094	5	3	6	3	14	22
2009	12	8	22	468	492	1,234	2	0	2	1	4	11
2010	13	5	23	546	587	1,457	2	3	3	2	13	28
Total	61	37	123	2,887	3,212	8,219	14	23	34	8	58	112

Table 9-4. Triple Helix sectorial outputs in South Korea

	U			I			G		
	d	F	g	d	F	g	d	f	g
2001	12,836	2,416	12,221	271	32	246	3,107	513	2,740
2002	14,400	2,946	13,628	311	41	260	3,238	606	2,810
2003	17,685	3,703	16,732	334	65	298	3,899	804	3,322
2004	19,595	3,909	18,543	391	68	342	4,108	787	3,502
2005	22,412	4,534	21,207	440	55	380	4,853	901	4,126
2006	25,114	5,055	23,845	478	67	398	5,390	996	4,621
2007	30,263	5,557	28,884	561	68	488	6,591	1,049	5,682
2008	30,939	6,195	29,349	526	46	422	6,023	1,152	5,067
2009	33,626	6,964	31,863	399	86	381	6,186	1,207	5,105
2010	34,325	7,823	32,371	381	67	289	6,478	1,305	5,240
Total	241,195	49,102	228,643	4,092	595	3,504	49,873	9,320	42,215

Table 9-4 (continuous). Triple Helix sectorial outputs in South Korea

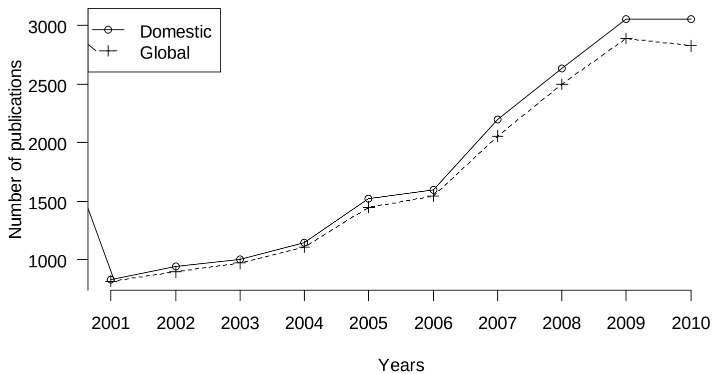
	UI			UG			IG			UIG		
	d	f	g	d	f	g	d	f	g	d	f	g
2001	276	32	334	2,160	497	3,246	72	11	85	57	17	102
2002	343	45	432	2,551	599	3,853	71	13	89	87	16	136
2003	463	44	547	3,339	711	4,978	78	24	103	106	21	180
2004	476	55	597	3,728	842	5,502	100	15	115	129	26	199
2005	541	53	654	4,258	1,065	6,369	127	19	141	119	30	197
2006	615	79	772	4,752	1,084	6,931	150	16	167	157	35	245
2007	742	70	888	5,282	1,300	7,804	113	14	134	192	45	290
2008	850	70	998	6,084	1,479	8,852	128	23	145	190	51	313
2009	962	89	1,144	6,989	1,716	10,062	136	32	157	255	64	392
2010	994	86	1,156	7,658	1,969	11,106	141	33	157	255	75	409
Total	6,262	623	7,522	46,801	11,262	68,703	1,116	200	1,293	1,547	380	2,463

Table 9-5. Triple Helix sectorial outputs in West African Countries

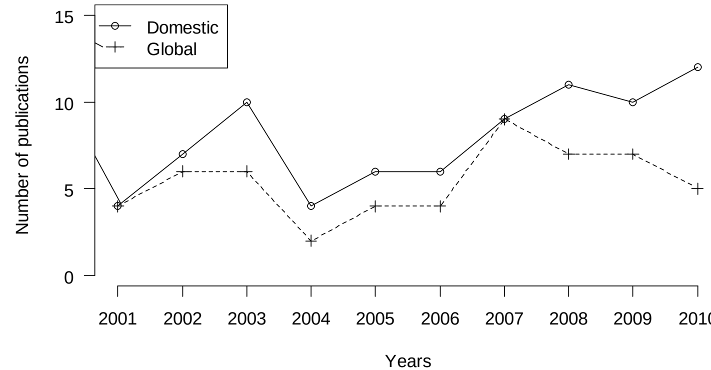
	U			I			G		
	d	f	g	d	f	g	d	f	g
Benin	471	536	422	0	1	0	600	197	262
Burkina Faso	355	688	409	1	1	1	980	258	391
Cape Verde	13	23	15	3	0	0	25	6	5
Cote d'Ivoire	686	467	588	1	0	0	678	277	412
Gambia	5	280	227	2	0	1	214	141	202
Ghana	1,684	1,174	1,446	23	4	11	1,050	368	505
Guinea	40	61	40	3	2	3	161	41	66
Guinea Bissau	3	15	3	0	0	0	174	102	113
Liberia	12	15	14	0	0	0	23	14	16
Mali	442	414	352	0	2	0	498	181	244
Niger	194	199	172	0	0	0	297	127	177
Nigeria	13,409	2,489	12,540	43	29	33	1,430	737	1,043
Senegal	932	830	887	3	10	3	1032	434	665
Sierra Leone	57	59	57	3	1	2	53	14	21
Togo	210	143	173	1	0	0	166	59	124

Table 9-5 (continuous). Triple Helix sectorial outputs in West African countries

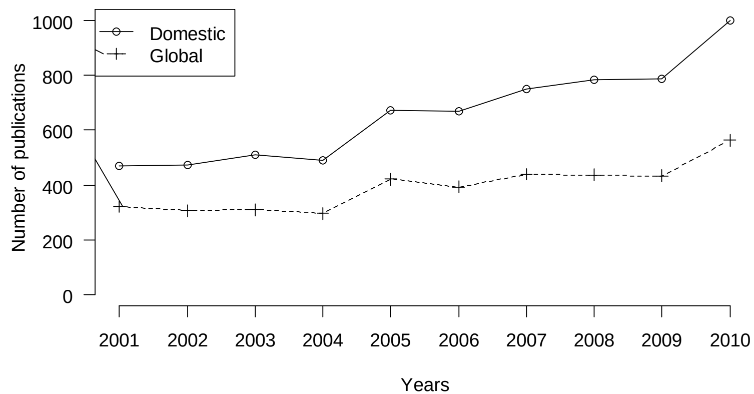
	UI			UG			IG			UIG		
	d	f	g	d	f	G	d	f	g	d	f	g
Benin	0	1	1	95	321	624	0	3	4	0	4	4
Burkina Faso	0	2	2	165	480	953	0	4	5	0	3	3
Cape Verde	0	0	0	1	18	28	0	1	1	0	0	3
Cote d'Ivoire	0	2	2	146	363	643	0	2	2	0	4	5
Gambia	0	2	2	5	333	388	0	1	1	0	3	4
Ghana	7	11	23	407	674	1,416	7	4	5	0	17	33
Guinea	0	0	1	11	102	139	0	1	2	0	2	2
Guinea Bissau	0	0	0	13	92	111	0	0	0	0	0	0
Liberia	0	0	0	4	14	21	0	0	0	0	0	0
Mali	0	1	2	86	339	585	0	1	0	0	16	18
Niger	0	0	0	20	132	246	0	1	1	0	0	0
Nigeria	44	16	84	1506	805	2,980	14	6	11	7	24	48
Senegal	0	6	10	186	530	913	0	5	7	0	6	10
Sierra Leone	0	1	2	9	24	54	0	0	0	0	0	1
Togo	0	1	2	27	85	133	0	1	1	0	1	1



(a) University's domestic and global outputs

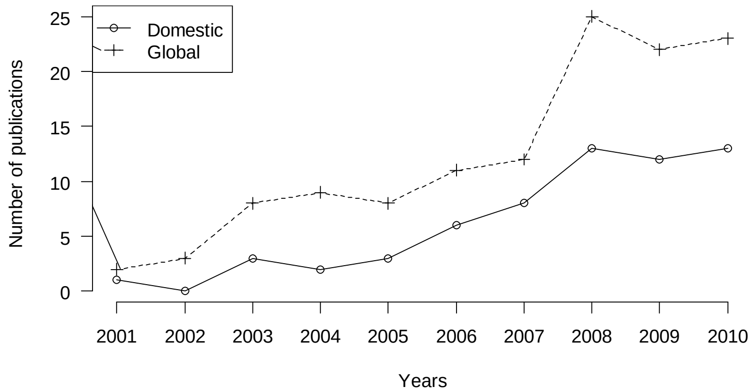


(b) Industry's domestic and global outputs

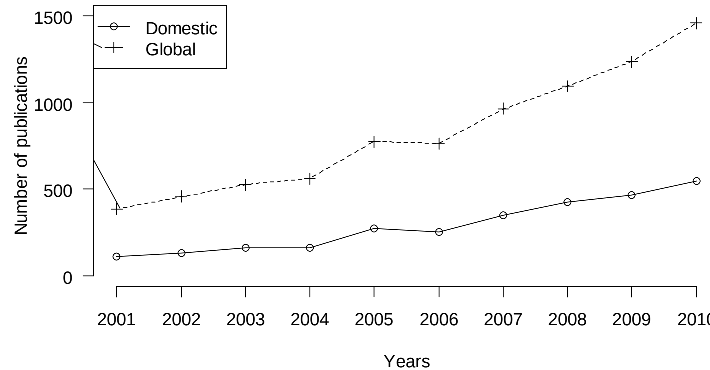


(c) Government's domestic and global outputs

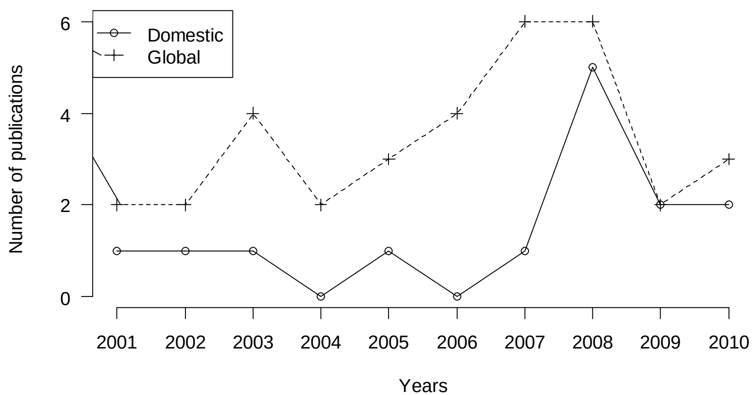
Figure 9-5 Relative positions of the Triple Helix's sectorial domestic and global outputs in West Africa



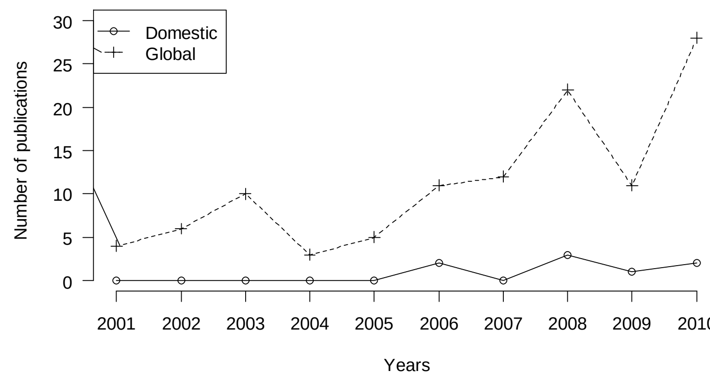
(a) University and Industry collaboration



(b) University and Government collaboration

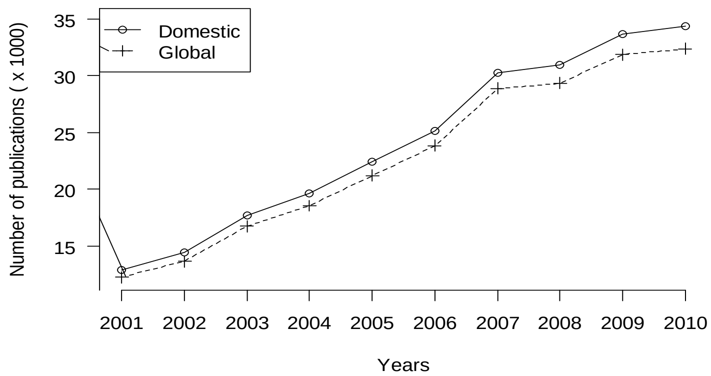


(c) Industry and Government collaboration

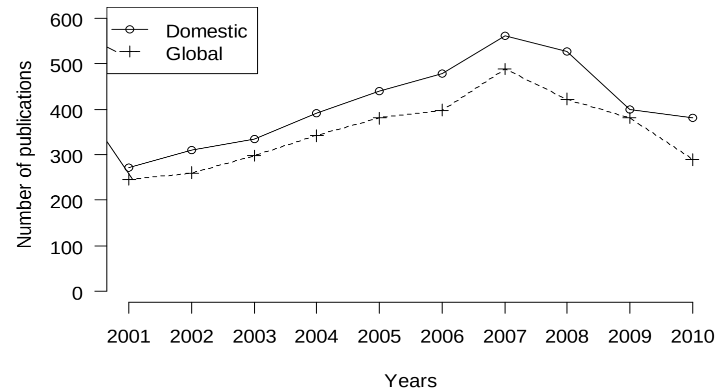


(d) University, Industry and Government collaboration

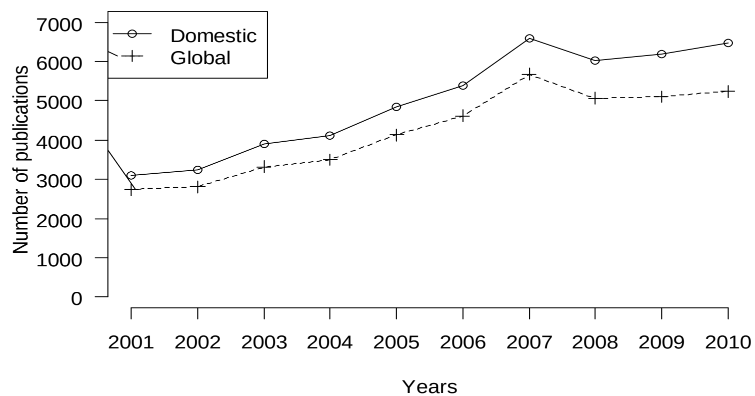
Figure 9-6 Comparison of the Triple Helix's sectorial domestic and global collaboration in West Africa



(a) University’s domestic and global outputs

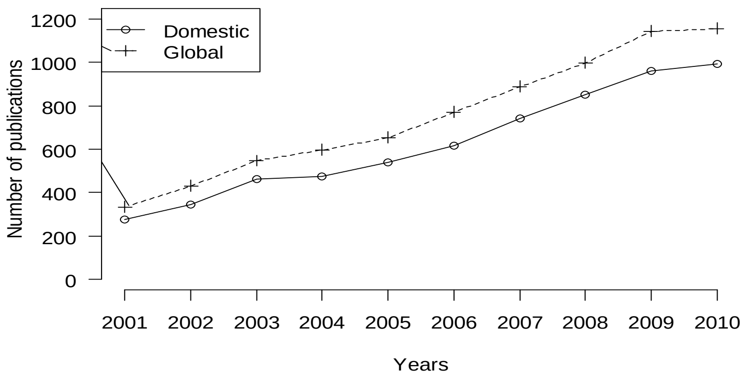


(b) Industry’s domestic and global outputs

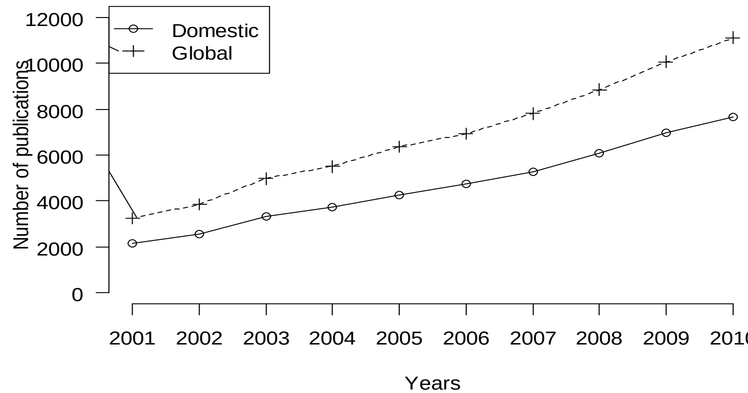


(c) Government’s domestic and global outputs

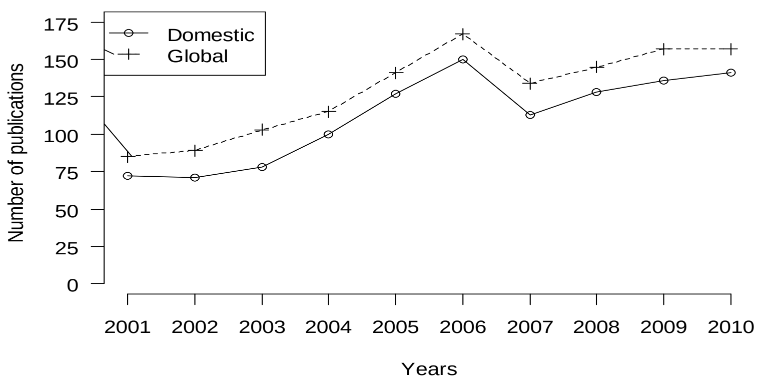
Figure 9-7 Comparison of the Triple Helix’s sectorial domestic and global outputs in South Korea



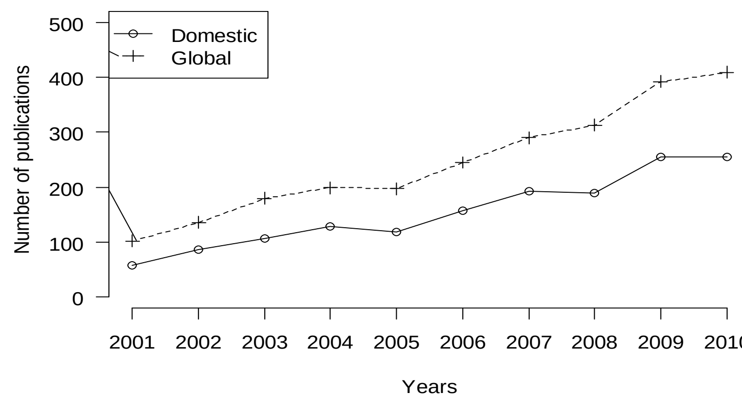
(a) University and Industry collaboration



(b) University and Government collaboration



(c) Industry and Government collaboration



(d) University, Industry and Government collaboration

Figure 9-8 Comparison of the Triple Helix's sectorial domestic and global collaboration in South Korea

9.3.3. Mutual information and transmission power time series

The mutual information and the transmission power time series are presented in Table 9-6 for West Africa and Table 9-7 for South Korea. They are related to the domestic, foreign and global levels. The mutual information values reveal that there is synergy within the considered innovation systems over the period of study at all levels. For the two areas under consideration, the curves of the three levels don't show the same relative positions over the period. In the case of South Korea, the domestic mutual information has the highest (absolute) value and decreased, except in 2009 where it took the median position. The global mutual information is lower (in absolute value) than the domestic one over the period; the foreign mutual information has either the top position or the median one (Figure 9-9). In the case of West Africa however, the relative positions of the curves are no longer identic (Figure 9-10). Indeed, the foreign mutual information has the highest (absolute) value except in 2001 and 2006 where it has the lowest. The domestic mutual information has the highest absolute value in 2001 and 2006 and keeps the median position over the rest of the period. The global mutual information gets the lowest absolute value over the period except 2001 and 2006.

In summary, globally, the foreign mutual information is higher (in absolute value) than the domestic one in the case of West Africa; but the South Korean innovation system exhibits an opposite pattern. In other words, the synergy operates more at the foreign level than at the domestic one in the case of West Africa but the reverse is recorded in the case of South Korea. These results suggest that the South Korean domestic system is more integrated than the 'foreign' one and that the West African system is less integrated than the 'foreign' one. It means that West Africa is very dependent on foreign partners, whereas this is much less the case for South Korea. At a country's level, innovation actors are submitted to the same rules and policies; they have the same domestic socioeconomic backgrounds and research agendas. On the other side, the foreign actors come from different countries; they are submitted to different policies and research agendas; therefore, the cohesion in their actions could not have the same strength as in the case of national actors. West African institutional partners even coming from different horizons seem more organised than the West Africa-based innovation actors.

At individual countries level, five countries (namely Benin, Guinea Bissau, Liberia, Mali and Niger) have a null domestic mutual information and transmission power; the remaining countries have all negative mutual information (Table 9-8). The foreign mutual information divided the West African countries into three classes: i) the ones with negative mutual information (10), ii) the ones with null mutual information (2) and iii) the ones with positive mutual information (3). The foreign mutual information is higher (in absolute value) than the domestic one in four countries: Benin, Mali, Nigeria and Senegal. Whereas Benin and Mali have a null domestic mutual information, Nigeria and Senegal have not. As a result, ten countries could be said have an integrated national innovation system: Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Sierra Leone and Togo

The global transmission power is highest in the case of South Korea. The foreign transmission power's relative position has changed over the period: it was the lowest over the period, except in 2004 and 2009 where it was median; it has interchanged its position with the domestic transmission power (Figure 9-11). The same global trend was registered in the case of West Africa: the global transmission power is higher than the domestic one but the foreign changed positions over the period (Figure 9-12). The mutual information measures the quantity of information common to the random variables in the system (Shannon, 1948, p. 410). It then measures the quantity of information or knowledge shared within the innovation actors. The transmission power is "the strength of the information flow within the system or between its actors." (Mêgnigbêto, 2014a, p. 287). Therefore, the knowledge sharing is more efficient in the global system than the domestic one, for both South Korea and West Africa. The global system ensures a better knowledge circulation among innovation actors.

As we may note, the scientific production of the African region is too weak (30,000 records in a 10-year period means 300 records a year, whereas South Korea produces more than 30,000 records a year) to allow analyses that could yield for any definitive conclusion. However, studying the structure of research collaboration in the West African region and countries may help in identifying explanation to these results.

Table 9-6. Mutual information (T_{uig}, in mbits) and transmission power (τ) for West Africa at domestic, foreign and global levels.

Year	Domestic		Foreign		Global		$\frac{\tau_g - \tau_d}{\tau_d}$ (%)
	T_{uig}	τ_d	T_{uig}	τ_f	T_{uig}	τ_g	
2001	−20.23	3.22	−17.603	5.17	−18.029	6.4	98.76
2002	−29.812	4.99	−39.916	12.35	−23.39	9.55	91.38
2003	−36.401	6.37	−41.408	14.26	−19.288	8.76	37.52
2004	−16.608	3	−23.915	8.72	−6.497	3.16	5.33
2005	−17.413	3.38	−30.6	9.09	−9.648	4.62	36.69
2006	−18.789	3.59	−7.668	2.93	−9.441	4.69	30.64
2007	−18.564	3.92	−22.536	7.94	−14.643	7.84	100.00
2008	−17.86	4.11	−20.783	8.53	−10.203	6.14	49.39
2009	−15.459	3.78	−21.543	9.14	−9.73	6.46	70.90
2010	−17.613	4	−29.975	12.55	−7.818	4.86	21.50
2001-2010	−19.411	3.96	−24.716	9.14	−11.636	6.1	54.04

Table 9-7. Mutual information (T_{uig}, in mbits) and transmission power (τ) for South Korea at domestic, foreign and global levels.

Year	Domestic		Foreign		Global		$\frac{\tau_g - \tau_d}{\tau_d}$ (%)
	T_{uig}	τ_d	T_{uig}	τ_f	T_{uig}	τ_g	
2001	-58.151	15.32	-41.944	13.24	-49.904	17.45	13.90
2002	-59.328	16.81	-42.293	13.54	-46.684	18.08	7.56
2003	-52.915	15.77	-49.976	14.71	-43.775	18.04	14.39
2004	-54.57	16.75	-51.463	17	-44.625	18.93	13.01
2005	-52.934	15.86	-38.124	13.43	-43.132	17.97	13.30
2006	-51,671	15,61	-42,402	14,45	-40,816	16,86	8,01
2007	-54,291	15,75	-41,293	15,13	-44,681	17,55	11,43
2008	-47,751	15,8	-26,366	9,97	-36,78	17,07	8,04
2009	-35,686	12,84	-37,811	15,03	-31	15,85	23,44
2010	-33,218	12,19	-28,651	11,96	-23,898	12,93	6,07
2001-2010	-48,036	15,17	-38,561	13,89	-38,685	17	12,06

Table 9-8. Mutual information (T_{uig}, in mbits) and transmission power (τ) for West African countries at domestic, foreign and global levels.

Years	Domestic		Foreign		Global		$\frac{\tau_g - \tau_d}{\tau_d}$ (%)
	T_{uig}	τ_d	T_{uig}	τ_f	T_{uig}	τ_g	
Benin	0	0	-5.959	2.63	0.692	0.04	---
Burkina Faso	-6.198	1.3	-3.761	1.87	-3.554	3.53	171.54
Cape Verde	-221.483	25.21	19.9	1.3	5.377	0.32	26.93-
Cote d'Ivoire	-6.427	1.03	-0.159	0.07	-0.129	0.07	-93.20
Gambia	-26.153	16.81	-0.026	0.02	-8.342	6.11	-63.65
Ghana	-41.054	7.77	-12.186	5.92	-18.503	13.78	77.35
Guinea	-67.516	12.3	-48.626	35.08	-39.014	36.68	198.21
Guinea Bissau	0	0	0	0	0	0	---
Liberia	0	0	0	0	0	0	---
Mali	0	0	-22.132	11.27	-1.934	1.52	---
Niger	0	0	1.789	0.11	0.825	0.05	---
Nigeria	-14.312	5.66	-41.725	13.6	-11.189	7.98	40.99
Senegal	-12.076	1.85	-29.931	11.23	-7.399	3.51	89.73
Sierra Leone	-112.699	15.72	-44.177	18.16	-58.585	34.51	119.53
Togo	-19.513	2.78	0.49	0.03	0.045	0	100

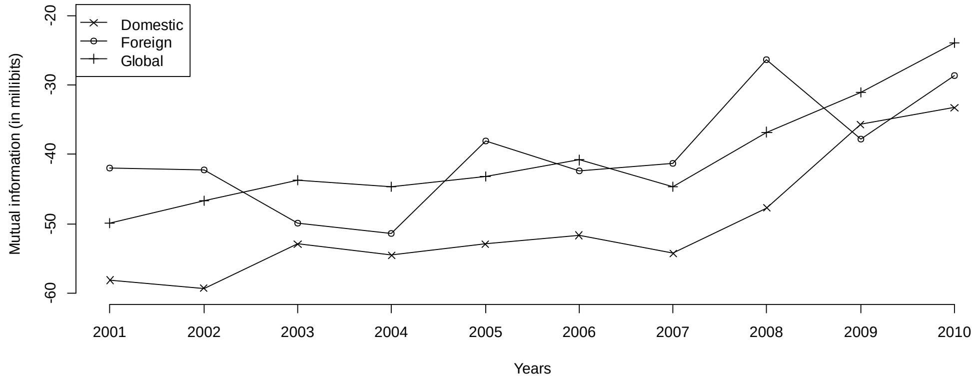


Figure 9-9 Domestic, foreign and global mutual informations of South Korea.

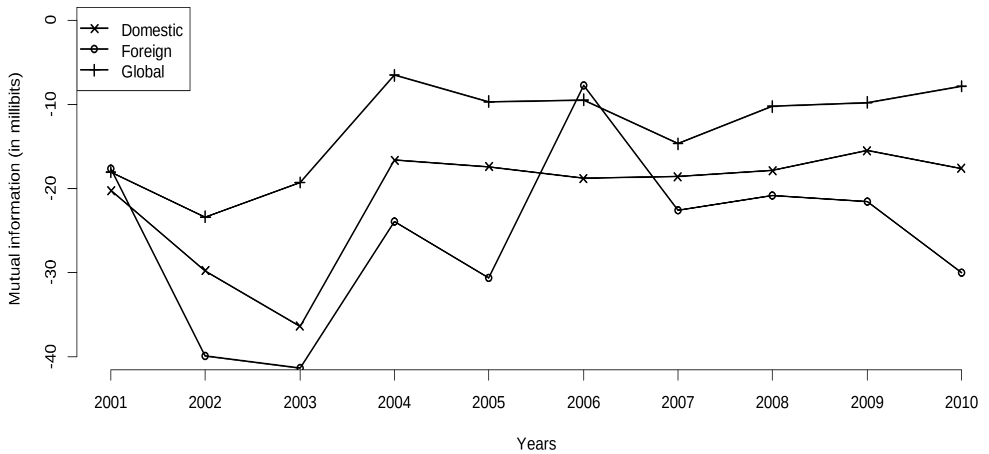


Figure 9-10 Domestic, foreign and global mutual informations of West Africa.

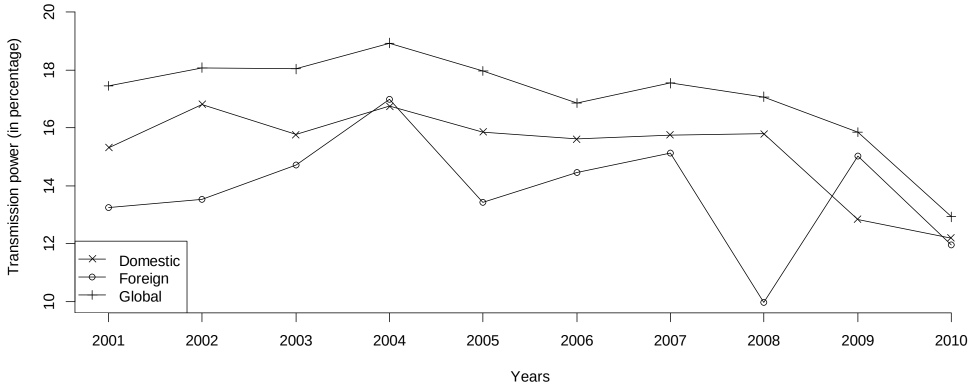


Figure 9-11 Domestic, foreign and global transmission power for South Korea.

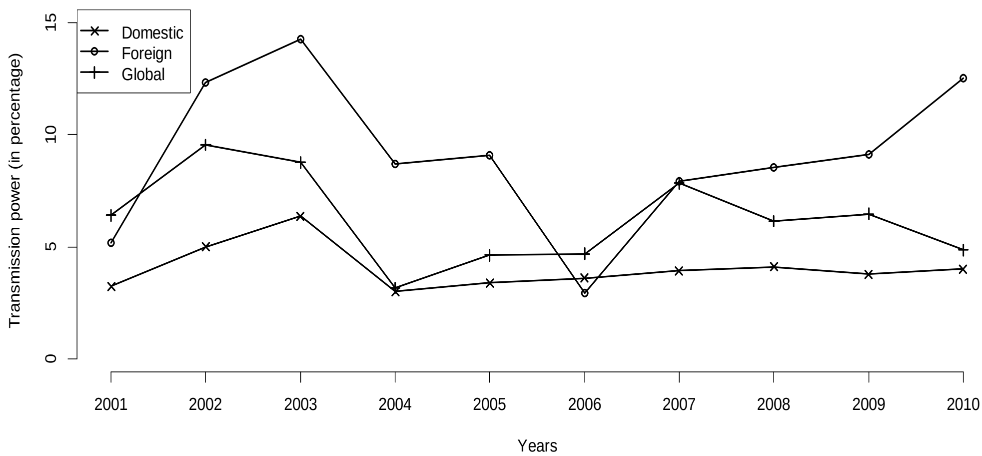


Figure 9-12 Domestic, foreign and global transmission power for West Africa.

9.3.4. Effect of international collaboration

The effect of the international collaboration on the knowledge flow is computed in the last columns of Table 9-6 and Table 9-7 and displayed in Figure 9-13. If South Korea has gained a little with regard to its domestic transmission power (7 – 24%, with an average of 12.7% over the ten-year period), the involvement in international collaboration has even doubled the West African knowledge circulation capacity. The region has gained from 5.33% to 100% of its knowledge sharing capacity with an average of 54.04% over the 10-year period.

As regarding the effect of international collaboration, West African countries are also divided into three categories: i) the one comprising countries with undefined effect because they have a null domestic transmission power (Benin, Guinea Bissau, Liberia, Mali, and Niger), ii) the one comprising countries with a positive effect (Burkina Faso, Cape Verde, Ghana, Guinea, Nigeria, Senegal, Sierra Leone and Togo), and iii) the last comprising countries with a negative effect (Cote d'Ivoire, and Gambia). The undefined effect is due to the formula used. The positive effect indicates that the international collaboration has increased the knowledge flow within the considered national innovation systems and the negative effect is quite surprising. It indicates that the international collaboration has decreased the rate of knowledge circulation within the innovation system. How this might have occurred? We should underline that the countries considered have a weak innovation systems and a weak scientific output. This may limit our analysis and prevent from drawing any definite conclusion

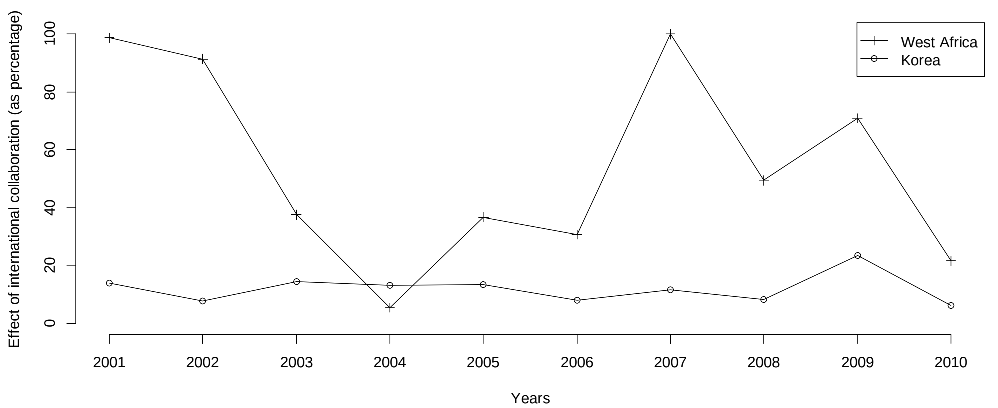


Figure 9-13 Effect of international collaboration on transmission power in South Korea and West Africa.

9.4. Discussion

West Africa and South Korea display opposite pattern with regard to the relative positions of the foreign and domestic mutual informations curves. Indeed, whereas the domestic mutual information is higher in absolute value than the foreign one in the case of South Korea, the reverse is recorded for West Africa. According to (Leydesdorff, 2003, 2008), when the mutual information is negative, it indicates the level of synergy within a system, the extent to which a system is self-organized. This result leads to the conclusion that the West African innovation system is less integrates than the set of its institutional partners considered as coming from the same country, and conversely that the South Korean innovation system is more integrated by itself. In fact, South Korea has strengthened its national innovation system after years of benefiting from international collaboration (Mêgnigbêto, under review, 2015c, p. 21) following changes in its policies over decades (Kwon et al., 2012). The stead investment in research and development may have strengthened collaboration between innovation actors at the country level and explains the performance of South Korea (Mêgnigbêto, under review, 2015c, p. 21). It illustrates the efforts made by South Korea to catch-up with leading economies (OECD, 2009, p. 13).

West Africa is a "region" composed with 15 countries. It is also an economic integration area with "supranational" institutions that have the role to conceive and apply policies at regional level. Even though the ECOWAS has formulated sectorial policies (e.g. in the fields of agriculture, Industry, energy, etc.), it is recently, in 2012, that the Economic Community of West African States Policy on Science and Technology (ECOPOST) was adopted. Actually it is hard to know the actions executed and the progress achieved toward a regional innovation system. Furthermore, not all ECOWAS Member States have a science and technology policy (Oti-Boateng, 2010).[76] Globally, the West African national innovation system is hindered by many factors among which are : the instability of the institutional framework, the inadequate coordination within the system, the lack of coordination between research programs and research activities, the lack of optimal use of human resources and loss of motivation of researchers, the lack of human and financial resources and equipment, the weaknesses in the institutional framework, the lack or weaknesses in the actors network, the weak improvement of research status, the insufficiencies or inadequacies of funding and equipment (cf. African Union, Economic Community of the West African States, United Nations Economic Commission for Africa, & United Nations, Educational, Scientific and Cultural Organisation, 2011, pp. 4–5; Mêgnigbêto, 2013e, p. 1115). Consequently, research in this part of the world is driven by foreign actors, and not by national or regional agendas. Even the intraregional collaboration is driven by international organisations or institutions with national representations in countries of West Africa (Mêgnigbêto, 2013e, p. 1133). That explains the high rate of international collaboration in the West African science (about 50% against 21% for South Korea); that also explains why the West African domestic mutual information is weaker (in absolute value) than the foreign one.

In our interpretation, the relative positions of the South Korean mutual information at the foreign and domestic levels seem to be the normal one. Indeed, a national system should be more integrated than a set of institutions from different horizons (named here 'foreign') because the components of the former are ruled by the same policies and have the same research agendas. This normal situation was also registered by Shin et al. (2012) for Saudi Arabia.

West Africa doesn't appear like a single unit of analysis; indeed, member countries do not exhibit the same pattern. Some are more integrated and others less than their

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[76] UNESCO distinguished eight ECOWAS Member States in three groups: those who have national STI policy (1), incomplete/nonfunctional out dated STI policies (2) and, those without any STI policy (6) (Oti-Boateng, 2010, p. 4).

partners. In other words, some countries are affected positively by international collaboration (e.g. Burkina Faso, Ghana and Nigeria) and others negatively (e.g. Gambia, Cape Verde, Cote d'Ivoire). However, the size of the data may have affected the West African results at both regional and national levels. Therefore, the resulting analysis could not be confident. The large variability of the effect of international collaboration on knowledge sharing in West Africa is an illustration.

The main result of this research is that the international collaboration the two areas under study involved in affected the synergy at their domestic level and also how knowledge is created and flows between innovation actors. In the case of South Korea, international collaboration makes that the country gained about 20% of its domestic strength of information flow. In the case of West Africa, the effect goes up to 100%. The relative positions of the mutual informations and the transmission powers in the two areas indicate that the West African innovation system is less integrated than the set of its international partners.

9.5. Conclusion

The objective of this chapter was to measure the effect of international collaboration on the mutual information and how knowledge flows among innovations actors. We formulated two research questions: i) How to measure the synergy or knowledge contributed to abroad by an area's innovation actors due to their relations with their foreign partners? ii) What is the effect of international collaboration on knowledge flow within an innovation system? To answer these questions, we distinguished three levels of analysis: the domestic one grouping innovation actors based in the country under study, the foreign level grouping institutional partners and the global one merging the innovations actors from both domestic and foreign levels. We computed the mutual information and the transmission power of South Korea and West Africa for the three levels, then, we could derive the effect of international collaboration. We found that the foreign mutual information is higher (in absolute value) than the domestic one in the case of West Africa, and lower in the case of South Korea meaning that the South Korean innovation system is integrated by itself whereas the West African is less integrated that its foreign system. We also found that in the two areas, the global transmission power is higher than the domestic one meaning that international collaboration has strengthened knowledge sharing at the domestic level; in other words, the two areas has benefited from international collaboration in term of knowledge flow.

However, because mutual information measures information sharing, our study could not indicate the direction of the exchange. Indeed, by being involved in international collaboration, a country contributes to knowledge creation and circulation; by the same way, it receives knowledge from its partners as well; therefore, the effect of the international collaboration is both the contribution of the country and what he gains.

10. Conclusions

This thesis aims to measure the contribution of research to innovation. It uses the Triple Helix model of innovation, which postulates that innovation results from collaboration between three main actors, namely University, Industry and Government. The geographical framework for this thesis comprises the 15 West African countries, all members of the Economic Community of the West African States (ECOWAS), the largest regional integration space in this part of Africa.

10.1. Recall of the objectives and research questions

The specific objectives of this thesis are to:

1. describe the landscape of scientific publishing in West Africa by analysing the scientific output of the region with respect to annual research output, language and publication type, scientific fields and co-authorship.
2. study the collaboration pattern in West African scientific publishing by determining the annual collaboration rates of the West African countries and the main partner countries of West Africa in terms of country, region as well as continent;
3. determine the extent to which West African innovation actors collaborate towards knowledge creation and sharing both at country level and regional level;
4. propose a method to measure knowledge circulation among innovation actors; and,
5. measure the extent to which knowledge is created and shared between innovation actors both at individual country level and regional level.

In order to attain these objectives, the following research questions were formulated:

6. What are the characteristics of the scientific output in West Africa?
7. To which extent do West African countries collaborate with each other or with the rest of the world regarding scientific publishing?
8. How do innovation actors collaborate in scientific publishing in West Africa?
9. How can knowledge circulation among the innovation actors be measured?
10. How is knowledge produced and circulated within the West African innovation systems?

Bibliographic references of the scientific publications of the West African countries over a 10-year period (2001-2010) were collected from the Web of Science, an international multidisciplinary database. The landscape of scientific publishing in

West Africa was described and intraregional and international collaboration as well as collaboration between the main innovation actors (University, Industry and Government) were depicted. Next, the transmission power was proposed as an indicator of the Triple Helix relationships. This indicator was used to measure the knowledge flow within the West African innovation systems. Together with the mutual information, the transmission power was used in this thesis to study the profiles of six OECD countries (USA, Canada, France, Germany, Japan and South Korea); possible correlations with indicators used in knowledge-based economy assessment were investigated. Finally, a method to compute the effect of international collaboration on knowledge flow in an economy was proposed.

10.2. Research landscape in West Africa

Chapter 3 provides an answer to the first research question "What are the characteristics of the scientific output in West Africa?". The indicators used to describe the landscape of research are annual output, language and type of production, field of production, co-authorship, international collaboration rate, main partner countries, citable documents and h-index.

West Africa produced approximately 30,000 records (or 3,000 publications/year) over the decade 2001-2010. The production curve shows a linear increasing trend over this 10-year period. Nigeria, due to the size of its population and its larger number of (both public and private) universities, is the biggest science producer in West Africa, accounting for more than half (55%) of the total regional output. Ghana is ranked second (11%), followed by Senegal (9%), Cote d'Ivoire (6%) and Burkina Faso (6%). Together, these top-5 countries produced approximately 9 out of 10 West Africa-based papers, with the remaining 10 countries hence accounting for less than 10% of the region's production. These statistics show that the distribution of scientific output among the West African countries is highly skewed. The (vast) majority of the publications are articles that are written in English and belong to the fields of *Medicine and health sciences* and *Natural sciences*. There is an increasing trend towards co-authored papers within the region with half of the papers being co-authored with at least one non-West African researcher. The main partner countries are European and North American countries. Colonial ties explain the ranking of France and the United Kingdom as the top partners of the region.

Almost all West African publications are citable and approximately 60% received at least one citation. Overall, cited documents received an average of 10 citations; the median citation is 4, i.e., half of the cited documents received no more than 4 citations and the other half received at least 4 citations. The h-index of the West African scientific output over the period 2001-2010 is 100.

West Africa performs less well than Brazil, Russia, India, China or South Africa, taken individually, as far as its annual research output is concerned. Indeed, its annual production amounts to 3,000 Web of Science-indexed documents, whereas Brazil produced nine times, Russia ten times, India eleven times, China forty times and South Africa twice as many papers. West Africa's science depends more on international collaboration - mainly with Western countries - than Brazil, Russia, India, China or South Africa. This lesser performance of the region is explained by poor investments in science, technology and innovation: Africa in general has the weakest research infrastructure as compared with other continents, which is why West African researchers need to collaborate more with non-African researchers to benefit from funding or infrastructures to maintain their research capacity and advance in grade. As a consequence, West African countries cooperate less with each another.

10.3. Research collaboration in West Africa

Chapter 4 offers an answer to the second research question: "To which extent do West African countries collaborate with each other or with the rest of the world regarding scientific publishing?".

Over the 10-year period of study, the share of West African papers with only one author has diminished, whereas that of papers with six or more authors has increased; this trend illustrates the increased importance of collaboration in scientific publishing within the region. West Africa shares half of its publications with non-West African countries. Over the period of study, the number of papers resulting from international collaboration has increased, whereas the percentage curve shows a slow decrease. West Africa's main partner countries on the continent are South Africa (in the Southern Africa region), Cameroon (in the Central Africa region) and Kenya and Tanzania (in the Eastern Africa region). The main non-African partner countries are France, USA and the United Kingdom, together accounting for over 63% of the papers with a non-West African address. The international collaboration rate at the individual country level varies largely: 28% for Nigeria vs. >70% for each of the remaining countries. Some countries like Cape Verde, Guinea Bissau and Sierra Leone share more than 90% of their publications with their partner countries. The main partner countries of individual West African members remain the Western countries with, at the top, the former colonial powers.

West African countries cooperate less with each other (about 5% in average) and less with African and developing countries than they do with developed ones. The intraregional collaboration rate for individual countries varies from 3% to 31%. The weakest rate is registered for Nigeria and the highest for Niger.

10.4. Collaboration between innovation actors

The third research question: "How do innovation actors collaborate in scientific publishing in West Africa?" is dealt with in Chapter 5.

The scientific output in West Africa over the period 2001-2010 was produced by around 5,000 research institutions –both West Africa-based and non-West Africa-based. More than half are universities, approx. 40% are governmental bodies, less than 2% have industrial affiliations, and the remaining are non-governmental organisations, international organisations or non-classified institutions. At the regional level, University is the biggest science producer (around 60%) followed by Government (41%) and Industry (1%); however, at the national levels, Government is the top information producer in the majority of countries. The industrial share is very negligible because Industry in West Africa, due to various barriers, does not contribute much to research activities.

Taking into account West Africa-based affiliations only, University produced ~ 70% of the regional scientific papers, Government ~ 32% and Industry 0.52%. The research output of these three main innovation actors is increasing, although the number of industrial publications is still negligible. Consequently, bilateral collaboration between University and Government is more visible than that between University or Government and Industry. Collaboration between the three Triple Helix spheres was found only in Nigeria, which is the biggest science producer in the region and also the first economy of Africa – and hence also of the region – in terms of GDP.

The mutual information, which indicates the level of synergy between University, Industry and Government, varies from –13 to –32 millibits of information, with an average of – 19 millibits over the decade. The synergy between innovation actors in West Africa is weak compared to that of other countries like India (–78 millibits) or South Korea (–253 millibits), illustrating the low level of knowledge flow among actors in the region as far as scientific publishing is concerned. The weak production of the industrial sector affected its collaboration with University and Government and hence also impacted on the knowledge production and circulation among the innovation actors in the region.

At the individual country level, all 15 ECOWAS Member States have data on University-Government collaborations, whereas Industry established relations with Government or University only in Nigeria and Ghana, the region's two largest information producers.

10.5. Transmission power as an indicator of knowledge circulation

In Chapter 6, we introduce the notion of transmission power as an indicator to measure the knowledge flow within an innovation system. The chapter provides an answer to the fourth research question: "How can knowledge circulation among the innovation actors be measured?".

From a communication network point of view, the University-Industry-Government relationship system can be considered as an information source. An information source composed with n random variables may be split into 2^n or $2^n - 1$ "states", allowing calculation of the maximum entropy of the source, which is log(n). The mutual information depends on the values of the considered variables. In three dimensions, where the mutual information may be positive or negative, its upper bound is the system's entropy and the lower bound the system's entropy minus the sum of each variable's entropies. The transmission power is proposed as an indicator of the Triple Helix of University-Industry-Government relationships. It is equal to the division of the mutual information by its upper bound if positive and by its lower bound if negative. In this sense, the transmission power is the normalisation of the mutual information; it represents the fraction of the maximum value of the mutual information produced in a system. In other words, the transmission power is the part of the system's sharable information capacity that is really shared; it may be expressed as a percentage and measures the knowledge or information circulation rate within an innovation system.

10.6. Knowledge flow within the West African innovation system

Chapter 7 computed the transmission power for the West African region over the period 2001-2010 in order to measure the knowledge flow between University, Industry and Government at both national and regional levels, and as such provides an answer to the fifth research question "How is knowledge produced and circulated within the West African innovation systems?".

The results are indicative of the existence of synergy between the three actors, both at the regional and the national level. The transmission power varies from 2 to 6%, i.e., only 2 to 6% of the sharable information produced over the period 2001-2010 within the West African innovation system at the regional level is actually distributed. Over the decade, the average value of the transmission power is 3.75%, illustrating the low level of knowledge flow among actors in the region as far as scientific publishing is concerned. At individual country level, the transmission power varies from 0 to 25%. The highest value is registered for Cape-Verde (24.51%), followed by Sierra Leone (12.08%), Guinea (11.06%), Ghana (8.03%), Nigeria (7.58%), Togo (2.49%), Senegal (1.61%), Burkina Faso (1%) and Cote d'Ivoire (0.87%). The transmission power of the six remaining countries (Benin, Gambia, Guinea Bissau, Liberia, and Mali) is zero, meaning that there is no information exchange within the innovation system of these countries, possibly as a consequence of the extraversion of the research system within the region.

10.7. Transmission power and the knowledge-based economy

According to the Triple Helix theory, the mutual information is an indicator of the extent to which an economy is knowledge-based; therefore, the transmission power can be considered for the same purpose. Chapter 8 also contributes to answering the fifth research question "How is knowledge produced and circulated within the West African innovation systems?".

Mutual information and transmission power were used to profile six OECD members (USA and Canada in North America, France and Germany in Europe, and Japan and South Korea in Asia). The analyses focused on possible correlations between the transmission power and a number of indicators used to measure the knowledge-based economy (GDP growth rate, GDP per capita, number of researchers, GERD, HDI and TFP). The results showed that the six countries do not have the same pattern with regard to the selected indicators: while some countries exhibit a positive correlation regarding transmission power and a particular indicator, others show a negative correlation between transmission power and the same indicator. However, Japan and South Korea exhibit a strong positive correlation between transmission power and GERD on the one hand and transmission power and number of researchers on the other hand; they also display similar patterns when correlations with other selected indicators are considered. The specific situation of these two countries is due to the preponderance of domestic co-authorship in Japanese science and the efforts of strengthening the national innovation system at the South Korean level. In contrast, the four other countries are influenced by the international collaboration they are involved in.

The results did not allow to infer any evident relation between transmission power and the selected indicators, possibly because the transmission power captures a dynamic that is lacking in the other indicators. However, the results did reveal that the transmission power as measured by the method used provides information at country level only and is not appropriate to measure the added value of University, Industry and Government relationships created at the international level. Therefore, it cannot be used for absolute comparison of countries unless the synergy created abroad is taken into account by including University-Industry-Government relationships at the international level.

10.8. International collaboration and knowledge flow

Chapter 9 equally deals with the answering the fifth research question “How is knowledge produced and circulated within the West African innovation systems?”.

Three levels of analysis are distinguished to determine the effect of international collaboration on knowledge flow: the domestic level pooling the innovation actors within one country under study, the foreign level grouping the institutional partners and the global level merging the innovation actors from both domestic and foreign levels. The mutual information and transmission power were computed for South Korea and West Africa for the three levels over a ten-year period (2001-2010); subsequently, the effect of international collaboration was calculated. The foreign mutual information is higher (in absolute value) than the domestic mutual information for West Africa, and lower for South Korea, i.e., the South Korean innovation system is integrated by itself, whereas the West African one is less integrated than its foreign system. In the two areas, the global transmission power is higher than the domestic transmission power, implying that international collaboration has strengthened knowledge sharing at the domestic level; in other words, both South Korea and the West African region have benefited from international collaboration in term of knowledge flow. The results show that 3 to 7% of the sharable knowledge is really shared in the West African region. This share increases to 3-10% when the effect of international collaboration is considered.

Both domestic and foreign actors benefit from collaborations in the two areas in terms of knowledge sharing. Indeed, by being involved in international collaboration, a country contributes to knowledge creation and distribution and, in turn, also receives knowledge from its partners; therefore, the effect of the international collaboration is dual: it is reflected in what the country contributes and in what it gains.

10.9. Contribution of this thesis to the advancement of science

According to the Triple Helix model, the knowledge that circulates within a system contributes to the production of innovation. Our work consists in building an indicator to assess the amount of knowledge that is distributed among the innovation actors. In this sense, taking publications as unit of analysis, the global transmission power, expressed as a percentage of the total sharable knowledge, allows us to measure the amount of knowledge shared within an innovation system.

The transmission power, expressed as a percentage, is based on the mutual information used up to that point to characterize the relationships between University, Industry and Government. The mutual information is a scalar: it can be positive or negative. If it is positive, it indicates the extent to which an innovation system is centrally-controlled; if it is negative, it indicates the level of synergy within an innovation system. Consequently, the lower the mutual information, the higher the synergy within the system. We demonstrate that the mutual information has lower and upper bounds that also depend on the output of each sector and their bi- or trilateral collaboration; therefore, the variability of the mutual information depends on the variable considered. The transmission power is the normalisation of the mutual information; indeed, it is the mutual information divided by its lower bound when it is negative and by its upper bound when it is positive. The mutual information is the fraction of the maximum mutual information that is really produced and shared within the system. Therefore, it is the fraction of the information sharing capacity that is really shared within the system. We use it as an indicator of knowledge flow within an innovation system.

However, the mutual information at the domestic level does not tell us how much the innovation actors of a given country contribute to the production of knowledge at the foreign level as a result of the international collaborations they are involved in. Therefore, we propose the global transmission power, which integrates both the domestic and foreign transmission power. The global transmission power is then higher than the domestic transmission power and indicates the quantity of knowledge that circulates within an innovation system. It is an indicator of the extent to which an economy is knowledge-based.

When the mutual information or the transmission power is computed as done in several studies, the synergy or the knowledge contributed by the innovation actors of a country at the international level as a result of international collaboration remains unconsidered. We have built a method that takes into account this kind of synergy or knowledge. We argue that our method more faithfully reflects the real properties of an innovation system in term of synergy and knowledge flow and that it can be used for comparison purposes. Applying our method to the West African region and South Korea revealed that the South Korean innovation system is more integrated by itself, whereas the West African one is less integrated than the set of its foreign institutional partners, illustrating the strong dependence of science in West Africa on international collaboration. Another conclusion that can be drawn from our comparative analysis is that international collaboration has strengthened knowledge sharing at the domestic level for both South Korea and West Africa, be it to a different extent; in other words, both areas have benefited from international collaboration in term of knowledge flow.

The main contributions of this work to the advancement of science are twofold: i) application of the transmission power as an indicator of knowledge production and sharing within an innovation system and ii) the distinction between domestic, foreign and global levels when computing the influence of international collaboration on knowledge creation and sharing within innovation actors at the individual country level.

10.10. Discussion

Building on the non-linear model of innovation, the Triple Helix theory postulates that innovation results from the interactions between three main actors, i.e., University, Industry and Government. The system ensures knowledge production, wealth generation and political control (Leydesdorff, 2016, p. 19). Particularly, the Triple Helix model postulates that the interactions between University, Industry and Government maintain a knowledge infrastructure that generates knowledge whose circulation among innovation actors leads to innovation (Leydesdorff & Etzkowitz, 2001). It focuses on the "overlay of communications and expectation" that reshapes the institutional arrangements among actors (Etzkowitz & Leydesdorff, 2000, p. 109).

The concept of interaction between innovation actors includes three basic ideas (OECD, 2002a, p. 15): i) competition, which is the interactive process where the actors are rivals and which creates the incentives for innovation; ii) transaction, which is the process by which goods and services, including technology embodied and tacit knowledge, are traded between economic actors; and iii) networking, which is the process by which knowledge is transferred through collaboration, co-operation and long term network arrangements. The Triple Helix model emphasizes collaboration.

The mutual information was used as an indicator of the Triple Helix relationships. It measures the level of synergy when it is negative, or how centrally controlled an innovation system is when it is positive. A negative mutual information value means the absence of domination of one actor over the two others; each acts autonomously within the legal framework to achieve its goals. Together with it partners, each innovation actor therefore collaborates to produce knowledge and share it in order to produce innovation; the economy is “knowledge-based”. When the Government-Industry relations dominate other bilateral relationships, the economy is a “political economy” (Khan & Park, 2011, p. 2453; Park et al., 2005).

The values of the West African regional mutual information vary from -24 to -6 millibits of information, indicating the existence of synergy between innovation actors. At country level, not all innovation systems exhibit synergy. The transmission power defined as the normalisation of the mutual information varies from 0 to 1 or from 0 to 100 if expressed as a percentage. It indicates the efficiency in information sharing between the Triple Helix actors or the strength of information or knowledge circulation among the innovation actors. West Africa’s transmission power values over the period 2001-2010 varied from 5 to 9%, i.e. 5 to 9% of the sharable information available within the West African region was actually shared at the regional level. In comparison, the South Korean transmission power values varied from 10 to 19% over the same period, i.e. twice the West African information flow.

International collaboration is known to influence knowledge flows, leading to the introduction of global, domestic and foreign mutual information and transmission power. According to Leydesdorff (2003), the mutual information does not only measure the level of synergy within an innovation system but also the level of integration of the actors within that system. Consequently, the distinction between domestic, foreign and global mutual information allows us to compare the level of integration of the West African University, Industry and Government system with that of their institutional partners, and the distinction between domestic, foreign and global transmission power enables us to measure how knowledge flows at the domestic level and what the influence of the institutional partners is. Our comparative analysis revealed that the institutional partners of South Korea are less integrated than its domestic innovation actors, whereas the opposite holds true for West Africa. Accordingly, West Africa has doubled its transmission power due to its external scientific relations, whereas South Korea has gained only up to 20% due to international collaboration.

West Africa’s specific profile with regard to the indicators of the Triple Helix (mutual information and transmission power) results from a number of problems related to Science, Technology and Innovation in the region. Whereas African countries have hardly invested in Science, Technology and Innovation, South Korea has strengthened its economy by investing heavily in research and innovation. For example, the GERD of the West African countries is still a long way from the target of 1%, while South Korea's GERD amounts to > 3.75% in 2010, which is far ahead of that of Japan (3%), Germany and USA (2.5%), France 2.25% and Canada (1.8%) (cf. OECD, 2014a). Considering the above-mentioned hindrances to the development of Science, Technology and Innovation in West Africa, we cannot really speak of the existence of an innovation system in the true sense at the regional level. At individual country level, "the image of an assemblage of fragile, somewhat disconnected and constantly under-resourced institutions is perhaps a more apt metaphor to describe the science arrangements" (Mouton, 2007, p. 15; Mouton & Waast, 2008, p. 39, 2009, p. 167). Indeed, a "system is a complex whole"; it requires not only individual elements, but coordination among them and sufficient means to make it function. An innovation system needs a legislative and institutional framework, sufficient equipment, human and financial resources as well as a solid agenda. At the West African regional level, there is a policy document, the ECOWAS Policy on Science and Technology, and a Commissioner is in charge of STI. However, the relations between the Commission and the national ministries in charge of research have not been defined to date: moreover, in 2016, the ECOWAS Commission is still seeking foreign financial assistance in order to implement the document policy conceived for the period 2013-2017.

As underlined previously, West Africa lacks human resources and research is mainly funded by foreign donors. Additionally, the region's research institutions and researchers are more instrumental in executing the activities pertaining to the partner's agendas than implementing their own agenda or that of their countries. Therefore, the "research system could collapse with the withdrawal of foreign partners" (Commission de la CEDEAO, 2012, p. 40). A few of the ECOWAS countries, like Burkina Faso, have a solid national research system (Commission de la CEDEAO, 2012). In general, developing countries imitate developed ones "rather slavishly and uncritically" (Mouton, 2007; Mouton & Waast, 2008, p. 37, 2009) but cannot always act like them.

The research and innovation problems in Africa listed in this thesis explain the lower output of African countries in general and West African ones in particular. For instance, the entire African continent produces ~ 1% of the global scientific output, while the Netherlands, a European country, produces more than the entire African continent (UNESCO Institute of Statistics, 2005). If the West African scientific output compared to the global output is low, the output of the Triple Helix actors is even lower; the industrial output in particular is negligible as a consequence of the low industrial development within the area, even though the region is endowed with natural resources, which are extracted, exported to and processed in Western countries. Only the *Medical and Health Sciences*, *Natural Sciences* and *Agricultural Sciences* are developed within the region as a consequence of lack of industrialisation and a legacy of the priorities colonial powers had given to science in the colonies. After their independence, however, African countries have not succeeded in boosting their industrialisation due to lack of sufficient investments in infrastructure and energy as shown by the Logistics Performance Index (Arvis et al., 2014).

Our analysis of applying the transmission power to the West African case, both at the regional and the national level, is based on limited data, which is why caution needs to be exercised when interpreting the West African data only. To overcome this problem, we included South Korea in our analysis, yielding more robust results and permitting a long term analysis compared to the West African case both at the domestic and the global level. The same applies to the effect of international collaboration on the distribution of knowledge.

10.11. Limitations of the study

The data analysed within the framework of this thesis are collected from an international database, the Web of Science. This database has been criticised for its bias towards the industrialised world and publications written in English (see e.g. Moravcsik, 1988). The geographic area covered in this thesis is West Africa, a region categorized within the developing world and composed of 7 English-speaking countries and 8 French- and Portuguese-speaking countries. Consequently, the scientific production of this part of the world is not fully searchable via the Web of Science. Of the 15 West African countries, only Nigeria has 7 journals indexed in the Web of Science. Therefore, the collected bibliographic data are those of West African scientists who appear mainly in journals based in Anglo-Saxon or West European countries.

Furthermore, it should be noted that the West African region is not a big science producer. As a consequence, its bibliographic data are very limited for many Triple Helix sectors. Therefore, any conclusion drawn needs to be interpreted with caution. This is why we decided to include data on another country, South Korea, to compute the effects of international collaboration on knowledge flow and compare these results with those of the region. Our comparative analysis shows that the South Korean situation is more stable than that of West Africa, because data for South Korea are seven times more extensive than those on West Africa.

A third limitation to this thesis pertains to the unit of analysis. Research encompasses many activities among which publications. Publications are merely one outcome of research activities, next to, for example, patents. All the variants of the non-linear model of innovation consider innovation as a result of collaborations between University, Industry and Government, the main innovation actors. Collaborations between these actors do not take the form of publications only. As pointed out by Katz and Martin (1997), research collaboration does not necessarily always lead to publications. In addition, collaboration between innovation actors may not only involve research activities, but also take the form of training, equipment, etc. As Mugabe (2011, p. 4) underlined, “linkages in a national system of innovation usually take different forms, including: joint research projects among public R&D institutions, joint technology development and transfer activities between public and private sector institutions, mobility and exchange of scientists and engineers, technology licensing agreements, and the sharing of information and technology infrastructure. Assessing the performance of a national system of innovation entails tracing the various institutional links and measuring the intensity of the interactions among various knowledge producers and economic actors." Therefore, the knowledge flow measured in this thesis does not represent the entire spectrum, since its covers only one aspect of collaboration.

The method used in this thesis here may also apply to patent data or other research outcomes, and one may also combine several research products in order to measure the circulation of knowledge globally within an innovation system.

10.12. Policy implications of this study

Taking into account the results of this thesis, the limitations of the study and the specific problems regarding research, innovation, universities, industry and governance in West Africa, we formulate the following recommendations. In order to facilitate efficient contribution of research to the advancement of the region, we suggest that:

i. the national authorities of countries lacking a proper Science, Technology and Innovation policy take the necessary steps to implement such a policy;
ii. the national authorities of countries with a Science, Technology and Innovation policy update it on a regular basis;
iii. national authorities allocate the necessary means for the execution of established research programmes;
iv. national authorities express their commitment to appropriate at least 1% of their GDP for science and technology funding;
v. both national and regional authorities set up dedicated authoritative institutions for Science, Technology and Innovation;
vi. regional authorities encourage and fund research activities that involve several institutions from different West African countries in order to increase intra-regional scientific collaboration;
vii. regional integration institutions create a regional database indexing scientific output published in regional sources as well as the output of researchers originating from West Africa but published in foreign sources;
viii. both national and regional authorities to invest in higher education and research institutions and as such contribute to Science, Technology and Innovation policy formulation and implementation at the national and the regional level;

ix. political leaders, scientists and the private sector commit themselves to cooperate in order to foster Science, Technology and Innovation in the West African region;
x. both national and regional authorities allocate sufficient financial resources to Science, Technology and Innovation on a programme basis
xi. both national and regional authorities clearly define sound research and innovation strategies or policies with clear indication of measurable targets and the role to be played by each stakeholder.

10.13. Directions for future research

This thesis proposed the transmission power as a metric for knowledge flow within an innovation system. This metric was applied to the case of West Africa and South Korea and the effect of international collaboration on knowledge flow was determined.

In order to measure the knowledge production and circulation, we applied the mutual information, which is related to Shannon's information theory. However, in more than two dimensions, like in the case of the Triple Helix relationships, the mutual information may be negative and as such is no longer valid as a Shannon-type measure. Krippendorf (2009a, 2009b) warned that the mutual information does not measure the unique interaction information in more than two dimensions; instead he proposed the interaction information, an indicator which is positive or null. However, Leydesdorff and Park (2014) argued that the mutual information, which measures both the negative synergy and the positive correlation in such a system, is a valid indicator to measure the synergy and the extent to which an economy is knowledge-based. The interaction information proposed by Krippendorff (2009a, 2009b) may be analysed for comparison purposes. The transmission power based on the interaction information may then be determined and the correlation with the transmission power based on the mutual information studied can be assessed.

Because collaboration in science is symmetric – e.g. when Country A collaborates with Country B, Country B also collaborates with country A with an equal number of papers – our calculation does not take into account the direction of the exchange, i.e., the amount of knowledge that flows from Country A to Country B is identical to that flowing in the reverse direction.

Recently, Yuret (2016) introduced the notion of direction in knowledge sharing based on co-authorship; he distinguished import and export of ideas. Following this theory, one may compute the outgoing and the incoming amount of knowledge an area imports or exports and, as a result, the outgoing and the incoming knowledge flows using the transmission power. In this way, one could determine if an area is a net importer or exporter of knowledge within a period of time.

11. References

Abass, A. (2013). *ECOWAS and the regional integration experiences in the world*. Praia: West Africa Institute.

Abbassi, A., Liaquat, H., & Leydesdorff, L. (2012). Betweeness centrality as a driver of preferential attachment in the evolution of research collaboration networks. *Journal of Informetrics*, *6*(3), 403–412.

Abramson, N. (1963). *Information theory and coding*. New York, etc.: McGraw-Hill.

Acosta, M., & Coronado, D. (2003). Science–technology flows in Spanish regions: an analysis of scientific citations in patents. *Resarch Policy*, *32*(10), 1783–1803.

Acosta, M., Coronado, D., & Fernandez, A. (2007). Exploring the quality of environmental technology in Europe: Evidence from patent citations. *Scientometrics*, *80*(1), 131–152.

Adams, J. (2012). Collaborations: The rise of research networks. *Nature*, *490*(7420), 335–336. http://doi.org/10.1038/490335a

Adams, J. (2013). The fourth age of research. *Nature*, *497*(7420), 557–560. http://doi.org/10.1038/490335a

Adams, J., Gurney, K., Hook, D., & Leydesdorff, L. (2014). International collaboration clusters in Africa. *Scientometrics*, *98*(1), 547–556. http://doi.org/10.1007/s11192-013-1060-2

Adams, J., King, C., & Hook, D. (2010). Global research report: Africa. Thomson Reuters.

Adams, J., King, C., Miyairi, N., & Pendlebury, D. (2010). *Global research report: Japan*. Philadelphia: Thomson Reuters.

Adams, J., Pendlebury, D., & Stembrifge, B. (2013). *Builging bricks: exploring the global research and innovation impact of Brazil, Russia, China, and South Korea*. ¨Philadelphia: Thomson Reuters.

African Development Bank. (2008). *Strategy for higher education, science et technology* (revised). Tunis: African Development Bank.

African Development Bank. (2011). *African development report : private sector development as an engine of Africa's economic development*. Tunis: African Development Bank.

African Development Bank, & African Development Fund. (2011). *Regional integration strategy paper for West Africa 2011 – 2015*. Tunis: African Development Bank.

African Development Bank, Organisation of Economic Co-Operation and Development, & United Nations Development Programme. (2015). *African economic outlook 2015: regional development and spatial inclusion*. Tunis-Paris-New York: AfDB - OECD - PNUD.

African Observatory of Science, Technology and Innovation. (2014). *Assessment of scientific production in the African Union: 2005–2010* (African Science, Technology and Innovation Outlook Bibliometric Series n° 1). Malabo: African Observatory of Science, Technology and Innovation. Retrieved from http://www.aosti.org/index.php/report/finish/5-report/15-assessment-of-scientific-production-in-the-african-union-2005-2010

African Union Commission, & New Zealand Ministry of Foreign Affairs and Trade. (2014). *African Union handbook: a guide for those working with and within the African Union* (1st edition). Addis Ababa: African Union Commission and New Zealand Ministry of Foreign Affairs and Trade. Retrieved from http://au.int/en/sites/default/files/MFA%20AU%20Handbook%20-%20Text%20v10b%20interactive.pdf

African Union, Economic Community of the West African States, United Nations Economic Commission for Africa, & United Nations, Educational, Scientific and Cultural Organisation. (2011). *Making science and technology information more accessible for Africa's development* (Workshop report) (p. 27). Abuja, Nigeria, 17-18 October 2011.

APEC Economic Committee. (2000). *Towards knowledge-based economies in APEC* (p. 204). Asia-Pacific Economic Cooperation.

Archibugi, D., & Sirilli, G. (2001). The direct measurement of techno logical innovation in business. In European Commission (Ed.), *Innovation and enterprise creation: statistics and indicators*. Brussels: European Commission.

Arellano-Valle, R. B., Contreras-Reyes, J. E., & Genton, M. G. (2013). Shannon entropy and mutual information for multivariate skew-elliptical distributions. *Scandinavian Journal of Statistics*, *40*(1), 42–62. http://doi.org/doi: 10.1111/j.1467-9469.2011.00774.x

Arkhangelskaya, A. A. (2011). BRIC- Africa cooperation in the multilateral system. IBSA – BRICS: rivals or allies. In *BRICS/IBSA-Africa relations: Turning threats to* *opportunity* (pp. 1–13). Uppsala: Russian Academy of Sciences. Retrieved from http://www.brics5.co.za/assets/Uppsala-June2011.pdf

Arvanitidis, P. A., & Petrakos, G. (2011). Defining knowledge-driven economic dynamism in the world economy: a methodological perspective. In P. Nijkamp & I. Siedschlag (Eds.), *Innovation, growth and competitiveness: dynamic regions in the knowledge-based world economy* (p. 380). New York: Springer.

Arvantis, R., Waast, R., & Gaillard, J. (2000). Science in Africa: A bibliometric panorama using PASCAL database. *Scientometrics*, *47*, 457–473.

Arvis, J.-F., Saslavsky, D., Ojala, L., Shepherd, B., Busch, C., & Raj, A. (2014). *Connecting to compete 2014: trade logistics in the global economy: the Logistics Performance Index and its indicators*. Washington DC: World Bank.

Australian Bureau of Statistics, & Trewin, D. (2002). *Measuring a knowledge-based economy and society: an Australian framework* (No. 1375.0) (p. 48). Camberra: Australian Bureau of Statistics.

Baldini, N. (2006). University patenting and licensing activity: a review of the literature. *Research Evaluation*, *15*(3), 197–207.

Bates, M. J. (2005). Information and knowledge: an evolutionary framework for information science. *Information Research*, *10*(4). Retrieved from http://www.informationr.net/ir/10-4/paper239.html

Batina, L., Gierlichs, B., Prouff, E., Rivain, M., Standaert, F.-X., & Veyrat-Charvillon, N. (2011). Mutual information analysis: a comprehensive study. *Journal of Cryptology*, *24*(2), 269–291. http://doi.org/10.1007/s00145-010-9084-8

Bierschenk, T., & Mongbo, R. (1995). La recherche en sciences sociales au Dahomey et au Bénin depuis les années 1970: l'hégémonie du paradigme développementiste. *Bulletin de l'APAD*, (10). Retrieved from http://apad. revues.org/1151.

Björneborn, L., & Ingwersen, P. (2004). Toward a basic framework for webometrics. *Journal of the American Society for Information Science and Technology*, *55*(14), 1216–1227. http://doi.org/10.1002/asi.20077

Blankley, W. O., & Booyens, I. (2010). Building a knowledge economy in South Africa. *South African Journal of Science*, *106*(11–12), 1–6. http://doi.org/10.4102/sajs.v106i11/12.373

Boisot, M., & Canals, A. (2014). Data, information and knowledge: have we got it right? *Journal of Evolutionary Economics*, *14*(1), 43–67.

Borchardt, K.-D. (2010). *The ABC of European Union law*. Luxembourg: Publications Office of the European Union,. Retrieved from http://europa.eu/documentation/legislation/pdf/oa8107147_en.pdf

Bordons, M., & Gomez, I. (2000). Collaboration networks in science. In B. Cronin & H. B. Atkins (Eds.), *A festschrift in honor of Eugene Garfield* (pp. 197–213). Medford: Information Today.

Boshoff, N. (2009). Neo-colonialism and research collaboration in Central Africa. *Scientometrics*, *81*(2), 413–434.

Boshoff, N. (2010). South–South research collaboration of countries in the Southern African Development Community (SADC). *Scientometrics*, *84*, 416–434.

Braun, T. (2001). Editorial. *Scientometrics*, *52*(2), 101.

Brookes, B. C. (1988). Comments on the scope of bibliometrics. In L. Egghe & R. Rousseau (Eds.), *Informetrics 87/88 : selected proceedings of the First International Conference on Bibliometrics and theoretical aspects of information retrieval* (pp. 29–41). Amsterdam: Elsevier Science Publishers.

Brookes, B. C. (1990). Biblio-, sciento-, infor-metrics??? What are we talking about? In L. Egghe & R. Rousseau (Eds.), *Informetrics 89/90 : selected proceedings of the Second International Conference on Bibliometrics and theoretical aspects of information retrieval* (pp. 31–43). Amsterdam/NewYork: Elsevier Science Publishers.

Bruin, R. E., & Moed, H. F. (1990). The uniformisation of addresses in scientific publications. In L. Egghe & R. Rousseau (Eds.), *Informetrics 89/90 : selection of papers submitted for the Second International Conference on bibliometrics, scientometrics and informetrics*. London, Ontario, Canada, 5-7 July 1989: Elsevier.

Buckland, M. (1991). Information as thing. *Journal of the American Society of Information Science*, *42*(5), 351–360.

Buclet, B., & Essayie, F. (2013). *Synthèse: atelier-rencontre sur l'efficacité de la R&D au niveau des politiques et pratiques institutionnelles en Afrique francophone*. Paris: OECD.

Callaert, J., Van Looy, B., Verbeek, A., Debackere, K., & Thijs, B. (2006). Traces of prior art: An analysis of non-patent references found in patent documents. *Scientometrics, 69(1), 3–20.*, *69*(1), 3–20.

CEDEAO. Acte additionnel A/SA.2/6/12 portant adoption de la Politique de la CEDEAO sur la science, la technologie et l'innovation et son plan d'action (2012).

Chen, D. H., & Dahlman, C. J. (2005). The knowledge economy, the KAM methodology and World Bank operations. *World Bank Institute Working Paper*, (37256).

Choi, S., Yang, J. S., & Park, H. W. (2015). The triple helix and international collaboration in science. *Journal of the Association for Information Science & Technology*, *66*(1), 201–212.

Commission de la CEDEAO. (2012). *Politique science, technologie et innovation (ECOPOST): 2013-2017*. Abuja: Commission de la CEDEAO.

Confraria, H., & Godinho, M. M. (2015). The impact of African science: a bibliometric analysis. *Scientometrics*, *102*(2), 1241–1268. http://doi.org/10.1007/s11192-014-1463-8

Courtial, J.-P. (1990). *Introduction à la scientométrie: de la bibliométrie à la veille technologique*. Paris: Anthropos.

Cover, T. M., & Thomas, J. A. (2006). *Elements of information theory* (2nd edition). Hoboken: J. Wiley.

Dahoun, A. M. (1999). Black Africa in the Science Citation Index. *Scientometrics*, *46*(1), 11–18.

Dahoun, A. M. C. (1997). Le statut de la science et de la recherche au Bénin: contribution à la sociologie des sciences des pays en développement. Berlin: Logos.

Davis, C. H. (1983). L'UNESCO et la promotion des politiques scientifiques nationales en Afrique Sub-saharienne, 1960-1979. *Études Internationales*, *14*(4), 621–638. http://doi.org/10.7202/701577ar

de Nooy, W., Mrvar, A., & Batagelj, V. (2005). *Exploratory analysis of social network with Pajek*. Cambridge: Cambridge University Press.

de Nooy, W., Mrvar, A., & Batagelj, V. (2011). *Exploratory social network analysis with Pajek* (revised and expanded second edition). Cambridge: Cambridge University Press.

Dolan, P., & Metcalfe, R. (2012). The relationship between innovation and subjective wellbeing. *Research Policy*, *41*(8), 1489–1498. http://doi.org/10.1016/j.respol.2012.04.001

ECOWAS. (1975). Treaty of the Economic Community of the West African States.

ECOWAS Commission. (1993). *Economic Community of West African States revised Treaty*. Abuja: ECOWAS Commission.

ECOWAS Commission. (2005). *Regional agricultural policy for West Africa: ECOWAP: make agriculture the lever of regional integration*. Abuja: ECOWAS Commission.

ECOWAS Commission. (2010a). *West African common industrial policy - WACIP*. Abuja: ECOWAS Commission.

ECOWAS Commission. (2010b). *West African common industrial policy - WACIP*. Abuja: ECOWAS Commission.

ECOWAS Commission. (2011a). *A proactive mechanism for chance: regional strategic plan (2011-2015)*. Abuja: ECOWAS Commission. Retrieved from http://www.spu.ecowas.int/wp-content/uploads/2010/06/Final_Draft-SP_doc__24_09_10.doc

ECOWAS Commission. (2011b). *ECOWAS vision 2020: towards a democratic and prosperous community*. Abuja: ECOWAS Commission.

ECOWAS Commission. (2012). *2012 annual report: integration and political stability in West Africa*. Abuja: Economic Community of the West African States.

ECOWAS Commission. (2015a). Achievements of ECOWAS at 40. ECOWAS Commission. Retrieved from http://www.ecowas.int/about-ecowas/achievements-of-ecowas-at-40/

ECOWAS Commission. (2015b). ECOWAS sectors. ECOWAS Commission. Retrieved from http://www.ecowas.int/ecowas-sectors/

ECOWAS Executive Secretary, & WAEMU Commission. (2006). *Regional integration fro growth and poverty reduction in West Africa: strategies and plan of action*. Abuja - Ougadougou: ECOWAS Executive Secretary - WAEMU Commission.

Egghe, L. (2005). Expansion of the field of informetrics: origins and consequences. *Information Processing and Management*, *41*, 1311–1316.

Egghe, L., & Rousseau, R. (1988). *Informetrics 87/88 : selected proceedings of the First International Conference on Bibliometrics and theoretical aspects of information retrieval*. Amsterdam/NewYork: Elsevier Science Publishers.

Egghe, L., & Rousseau, R. (1990a). *Informetrics 89/90 : selected proceedings of the Second International Conference on Bibliometrics and theoretical aspects of information retrieval*. Amsterdam/NewYork: Elsevier Science Publishers.

Egghe, L., & Rousseau, R. (1990b). *Introduction to informetrics: quantitative methods in library, documentation and information science*. Amsterdam/NewYork: Elsevier Science Publishers.

Eisemon, T. O. (1982). *The science profession in the Third World: Studies from India and Kenya*. Praeger Publishers.

Etzkowitz, H., & Dzisah, J. (2007). The Triple Helix of innovation: towards a university-led development strategy for Africa. *ATDF Journal*, *4*(2), 3–10.

Etzkowitz, H., & Leydesdorff, L. (1995). The Triple Helix---University-Industry-Government relations: a laboratory for knowledge-based economic development. *EEASST Review*, *14*(1), 14–19.

Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and '"Mode 2"' to a Triple Helix of university–industry–government relations. *Research Policy*, *29*(2), 109–123.

European Commission. (2010a). *Europe 2020: a strategy for smart, sustainable and inclusive growth* (Communication from the Commission No. COM(2010) 2020 final) (p. 35). Brussels: European Commission.

European Commission. (2010b). *European innovation scoreboard.* Luxembourg: Office for Official Publications of the European Communities.

European Commission. (2014). *Innovation Union scoreboard*. Luxembourg: Office for Official Publications of the European Communities.

European Commission - EUROSTAT. (2006). *Conference on knowledge economy: challenges for measurement, Luxembourg, 8–9 December 2005*. Luxembourg: European Commission, Joint Research Centre.

FAO Regional Office for Africa. (2014). *FAO statistical yearbook 2014: Africa food and agriculture*. Accra: FAO Regional Office for Africa.

Frietsch, R. (2008). Recent trends in innovation policy in Germany. Karlsruhe/Hamburg/Atlanta: ISI - GIGA - STIPA.

Gaillard, J. (2010). *Le système national de recherche scientifique et technique au Bénin : un état des lieux*. Paris: UNESCO.

GEA-African studies group, Garcia, J., & Seron, G. (2014). *ECOWAS regional integration processes and international cooperation*. Madrid: Spanish Agency for International Cooperation and Development.

Ghana. Ministry of environment, science and technology. (2010). *National science, technology and innovation policy*. Accra: Ministry of environment, science and technology.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge: the dynamics of science and research in contemporary societies*. Sage.

Glänzel, W. (2001). National characteristics in international scientific co-authorship relations. *Scientometrics*, *51*(1), 69–115.

Godin, B. (2005). *The linear model of innovation: the historical construction of an analytical framework* (Working Paper No. 30) (p. 36). Montréal, Québec, Canada: Institut National de la Recherche Scientifique.

Godin, B. (2006a). The knowledge-based economy: conceptual framework or buzzword? *The Journal of Technology Transfer*, *31*(1), 17–30.

Godin, B. (2006b). The linear model of innovation: the historical construction of an analytical framework. *Science, Technology & Human Values*, *31*(6), 639–667.

Godin, B. (2007). *National innovation system: the system approach in historical perspective* (Working paper No. 36) (p. 37). Montréal, Québec, Canada: Institut National de la Recherche Scientifique.

Godin, B. (2014). Invention, diffusion and linear models of innovation: the contribution of anthropology to a conceptual framework. *Journal of Innovation Economics & Management*, *3*(15), 11–37. http://doi.org/10.3917/jie.015.0011

Guns, R. (2013). The three dimensions of informetrics: a conceptual view. *Journal of Documentation*, *69*(2), 295–308. http://doi.org/10.1108/00220411311300093

Guns, R., & Rousseau, R. (2014). Recommending research collaborations using link prediction and random forest classifiers. *Scientometrics*, *101*(2), 1461–1473. http://doi.org/10.1007/s11192-013-1228-9

Harzing, A.-W. (2012). How to become an author of ESI Highly Cited Papers? Retrieved from http://www.harzing.com/esi_highcite.htm

Hirsch, J. E. (2005). An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(46), 16569–16572. http://doi.org/10.1073/pnas.0507655102

Hood, W. W., & Wilson, C. S. (2001). The literature of bibliometrics, scientometrics, and informetrics. *Scientometrics*, *52*(2), 291–314.

Horner, S. (1993). Rencontre avec Dr Mahbub ub Haq, conseiller spécial auprès de l'administrateur du PNUD. *Courrier ACP-UE*, *139*, 4–6.

Hou, H., Kretschmer, H., & Liu, Z. (2008). The structure of scientific collaboration networks in Scientometrics. *Scientometrics*, *75*(2), 189–202.

Ivanova, I. A., & Leydesdorff, L. (2014). Redundancy generation in Triple-Helix relations: modeled, measured, and simulated. *Scientometrics*, *99*(3), 927–948. http://doi.org/10.1007/s11192-014-1241-7

Ivanova, I. A., Strand, Ø., & Leydesdorff, L. (2014). Synergy cycles in the Norwegian innovation system: The relation between synergy and cycle values. *Available at SSRN 2492456*.

Jeenab, M., & Pouris, A. (2008). South African research in the context of Africa and globally. *Science Policy South African Journal of Science*, (104), 351_355.

Karahan, Ö. (2012). Input - output indicators of knowledge-based economy and Turkey. *Journal of Business, Economics & Finance*, *1*(2), 21–36.

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy*, *26*(1), 1–18.

Khan, F. G., & Park, H. W. (2011). Measuring the Triple Helix on the Web: longitudinal trends in the university-industry-government relationship in Korea. *Journal of the American Society for Information Science*, *62*(12), 2443–2455.

Kline, S. J. (1985). Innovation is not a linear process. *Research Management*, *28*(4), 36–45.

Krippendorff, K. (2009a). Information of interactions in complex systems. *International Journal of General Systems*, *38*(6), 669–680.

Krippendorff, K. (2009b). Ross Ashby's information theory: a bit of history, some solutions to problems, and what we face today. *International Journal of General Systems*, *38*(2), 189–212.

Krippendorff, K. (2014, January 22). Re: variables independence and mutual information. *Cybernetics Discussion Group CYBCOM*. Retrieved from https://hermes.gwu.edu/cgi-bin/wa?A2=ind1401&L=cybcom&F=&S=&P=23173

Kwon, K.-S. (2011). The co-evolution of universities' academic research and knowledge-transfer activities: the case of South Korea. *Science and Public Policy*, *38*(2), 493–503.

Kwon, K.-S., Park, H. W., So, M., & Leydesdorff, L. (2012). Has globalization strengthened South Korea's national research system? National and international dynamics of the Triple Helix of scientific co-authorship relationships in South Korea. *Scientometrics*, *90*(1), 163–176.

Le Boudec, J.-Y., Thiran, P., & Urbanke, R. (2013). *Sciences de l'information*.

Le Coadic, Y.-F. (1994). *La science de l'information* (2ème édition corrigée). Paris: Presses Universitaires de France.

Lebeau, Y. (1997). *Etudiants et campus du Nigeria: recomposition du champ universitaire et sociabilités étudiantes*. Karthala.

Leeuwen, van T. (2008). Testing the validity of the Hirsch-index for research assessment purposes. *Research Evaluation*, *17*(2), 157–160. http://doi.org/10.3152/095820208X319175

Leydesdorff, L. (1991). The static and dynamic analysis of network data using information theory. *Social Networks*, *13*(4), 301–345.

Leydesdorff, L. (2003). The mutual information of university-industry-government relations: an indicator of the Triple Helix dynamics. *Scientometrics*, *58*(2), 445–467.

Leydesdorff, L. (2008). Configurational information as potentially negative entropy: the Triple Helix model. *Entropy*, *10*(4), 391–410. http://doi.org/10.3390/e10040391

Leydesdorff, L. (2010a). Redundancy in Systems Which Entertain a Model of Themselves: Interaction Information and the Self-Organization of Anticipation. *Entropy*, *12*(1), 63–79. http://doi.org/10.3390/e12010063

Leydesdorff, L. (2010b). The knowledge-based economy and the Triple Helix model. *Annual Review of Information Science and Technology*, *44*(1), 365–417.

Leydesdorff, L. (2012a). The Triple Helix of university-industry-government relations. *Scientometrics*.

Leydesdorff, L. (2012b). The Triple Helix, Quadruple Helix, …, and an N-tuple of Helices: explanatory models for analyzing the knowledge-based economy? *Journal of the Knowledge Economy*, *3*(1), 25–35.

Leydesdorff, L. (2014, January 22). Re: variables independence and mutual information. *Cybernetics Discussion Group CYBCOM*. Retrieved from https://hermes.gwu.edu/cgi-bin/wa?A2=ind1401&L=cybcom&F=&S=&P=23043

Leydesdorff, L. (2016). Triple Helix models of innovation: are synergies generated at national or regional levels? *Hélice*, *5*(1), 19–20.

Leydesdorff, L., & Curran, M. (2000). Mapping university-industry-governement relations on the Internet: the construction of indicators for a knowledge bases economy. *Cybermetrics: International Journal of Scientometrics, Informatetrics and Bibliometrics*, *4*(1).

Leydesdorff, L., & Etzkowitz, H. (2001). The transformation of university-industry-government relations. *Electronic Journal of Sociology*, *5*(4). Retrieved from http://www.sociology.org/content/vol005.004/th.html

Leydesdorff, L., & Ivanova, I. A. (2014). Mutual redundancies in interhuman communication systems: steps towards a calculus of processing meaning. *Journal of the Association for Information Science and Technology*, *65*(2), 386–399. http://doi.org/10.1002/asi.22973

Leydesdorff, L., & Meyer, M. (2006). Triple Helix indicators of knowledge-based innovation systems. *Resarch Policy*, *35*(10), 1441–1449.

Leydesdorff, L., & Park, H. (2014). Can synergy in Triple Helix relations be quantified? A review of the development of the Triple Helix indicator. *Triple Helix: A Journal of University-Industry-Government Innovation and Entrepreneurship, 1*(1), 1–18. http://doi.org/10.1186/s40604-014-0004-z

Leydesdorff, L., Park, H. W., & Lengyelc, B. (2013). A Routine for Measuring Synergy in University-Industry-Government Relations: Mutual Information as a Triple-Helix and Quadruple-Helix Indicator. *Scientometrics*, *99*(1), 7–35. http://doi.org/10.1007/s11192-013-1079-4

Leydesdorff, L., Perevodchikov, E., & Uvarov, A. (2015). Measuring triple-helix synergy in the Russian innovation systems at regional, provincial, and national levels. *Journal of the Association for Information Science and Technology*, *66*(6), 1229–1238. http://doi.org/10.1002/asi.23258

Leydesdorff, L., & Sun, Y. (2009). National and international dimensions of the Triple Helix in Japan: university-industry-government versus international co-Authorship relations. *Journal of the American Society for Information Science*, *60*(4), 778–788.

Leydesdorff, L., Wagner, C., Park, H.-W., & Adams, J. (2013). International collaboration in science: the global map and the network. *El Profesional de La Información, January-February*, *22*(1), 87–94. http://doi.org/http://dx.doi.org/10.3145/epi.2013.ene.12

Leydesdorff, L., & Wagner, C. S. (2008). International collaboration in science and the formation of a core group. *Journal of Informetrics*, *2*(4), 317–325.

Leydesdorff, L., & Zawdie, G. (2010). The Triple Helix perspective of innovation systems. *Technology Analysis & Strategic Management*, *22*(7), 789–804.

Leydesdorff, L., & Zhou, P. (2013). Measuring the knowledge-based economy of China in terms of synergy among technological, organizational, and geographic attributes of firms. *Scientometrics*, *98*(3), 1703–1719.

Liang, L. M., Chen, L. X., Wu, Y. S., & Yuan, J. P. (2012). The role of Chinese universities in enterprise– university research collaboration. *Scientometrics*, *90*(1), 253–269.

Liu, Y. (2011). *The diffusion of scientific ideas in time and indicators for the description of this process* (Doctoral dissertation). University of Antwerp, Antwerp.

Liu, Y., Rousseau, R., & Guns, R. (2013). A layered framework to study collaboration as a form of knowledge sharing and diffusion. *Journal of Informetrics*, *7*(3), 651–664. http://doi.org/10.1016/j.joi.2013.04.002

Maclaurin, W. R. (1953). The sequence from invention to innovation and its relation to economic growth. *Quarterly Journal of Economics*, *67*(1), 97–111.

McGill, W. J. (1954). Multivariate information transmission. *Psychometrika*, *19*(2), 97–116.

Mêgnigbêto, E. (under review). Correlation between transmission power and some indicators used to measure the knowledge-based economy: case of six OECD countries. *Journal of the Knowledge Economy*.

Mêgnigbêto, E. (1998). Le traitement des particules nobiliaires: une expérience avec CDS/ISIS. *Documentaliste-Sciences de L'information*, *35*, 321–325.

Mêgnigbêto, E. (2012). Scientific publishing in West Africa: a comparison of Benin with Ghana and Senegal. In *Proceedings of STI 2012* (Vol. 2, pp. 589–600). Montréal: Science Metrix; Observatoire des sciences et des Technologies.

Mêgnigbêto, E. (2013a). International collaboration in scientific publishing: the case of West Africa (2001-2010). *Scientometrics*, *96*(3), 761–783. http://doi.org/10.1007/s11192-013-0963-2

Mêgnigbêto, E. (2013b). Intra-regional collaboration in the West African science. In Université d'Abomey-Calavi (Ed.), *IVème colloque de l'Université d'Abomey-Calavi*. Abomey-Calavi: Université d'Abomey-Calavi.

Mêgnigbêto, E. (2013c). Scientific publishing in Benin as seen from Scopus. *Scientometrics*, *94*(3), 911–928. http://doi.org/10.1007/s11192-012-0843-1

Mêgnigbêto, E. (2013d). Scientific publishing in West Africa: a comparison with BRICS. In S. Hinze & A. Lottmann (Eds.), *Translation twists and turns: science as a socio-economic endeavor: proceedings of STI 2013* (pp. 557–560). Berlin: Institute for Research Information and Quality Assurance - European Network of Indicators Designers.

Mêgnigbêto, E. (2013e). Scientific publishing in West Africa: comparing Benin with Ghana and Senegal. *Scientometrics*, *95*(3), 1113–1139. http://doi.org/10.1007/s11192-012-0948-6

Mêgnigbêto, E. (2013f). Scientific research in West Africa: a global view (2001-2010). *ISSI Newsletter*, *9*(1), 6–11.

Mêgnigbêto, E. (2013g). Triple Helix of university-industry-government relationships in West Africa. *Journal of Scientometric Research*, *2*(3), 54–62. http://doi.org/10.4103/2320-0057.135413

Mêgnigbêto, E. (2014a). Efficiency, unused capacity and transmission power as indicators of the Triple Helix of university-industry-government relationships. *Journal of Informetrics*, *8*(1), 284–294. http://doi.org/10.1016/j.joi.2013.12.009

Mêgnigbêto, E. (2014b). Information flow between West African Triple Helix actors. *ISSI Newsletter*, *10*(1), 14–20.

Mêgnigbêto, E. (2014c). Information flow within West African innovation systems. *Triple Helix: A Journal of University-Industry-Government Innovation and Entrepreneurship*, *1*(1), 1–13. http://doi.org/10.1186/s40604-014-0005-y

Mêgnigbêto, E. (2014d). La collaboration en matière de recherche scientifique et technique au Bénin : 2005-2009. *Revue Canadiennes de Sciences de L'information et de Bibliothéconomie - Canadian Journal for Information and Library Science*, *38*(3), 188–204.

Mêgnigbêto, E. (2014e). Transmission power as an indicator of innovation: Is there any relations between transmission power and economic performance ? In Université de Lomé (Ed.). Presented at the Journées scientifiques internationales de Lomé, Lomé: Université de Lomé.

Mêgnigbêto, E. (2014f). Transmission power in some particular cases of bi- or tri-dimensional complex systems. *Journal of Scientometric Research*, *3*(1), 37–45. http://doi.org/10.4103/2320-0057.143704

Mêgnigbêto, E. (2015a). Effect of international collaboration on knowledge flow within an innovation system: a Triple Helix approach. *Triple Helix: A Journal of University-Industry-Government Innovation and Entrepreneurship*, *2*(1). http://doi.org/10.1186/s40604-015-0027-0

Mêgnigbêto, E. (2015b). Evaluation de l'économie du savoir au niveau de la région ouest-africaine : une approche basée sur le modèle de la Triple Hélice. Presented at the Vème Colloque de l'Université d'Abomey-Calavi, Abomey-Calavi: Université d'Abomey-Calavi.

Mêgnigbêto, E. (2015c). Profiles of six OECD countries with regard to mutual information and transmission power. *ISSI Newsletter*, *11*(1), 16–23.

Mêgnigbêto, E., & Houzanmè, U. T. (2012). Radioscopie de la recherche scientifique au Bénin: une étude bibliométrique à travers Web of Science. *Revue Perspectives et Sociétés*, *3*(1), 180–206.

Meyer, M. (2012). Triple Helix indicator: a bibliometric perspective. *Hélice: The Triple Helix Association Newsletter*, *1*(2), 4–6.

Meyer, M., Grant, K., Morlacchi, P., & Weckowska, D. (2014). Triple Helix indicators as an emergent area of enquiry: a bibliometric perspective. *Scientometrics*, *99*(1), 151–174. http://doi.org/10.1007/s11192-013-1103-8

Meyer, M., Siniläinen, T., & Utecht, J. T. (2003). Towards hybrid Triple Helix indicators: a study of university-related patents and a survey of inventors. *Scientometrics*, *58*(2), 321–350.

Minega, C. E. (2015). *The role of higher education and research policy in the process of regional integration in West Africa and beyond: analysis of current issues, challenges and opportunities*. Praia: West Africa Institute.

Mitra, J., & Edmondson, J. (2015). *Entrepreneurship and knowledge exchange*. Routledge.

Moed, H. F. (1988). The use of on-line databases for bibliometrics analysis. In L. Egghe & R. Rousseau (Eds.), *Informetrics 87/88 : selected proceedings of the First International Conference on Bibliometrics and theoretical aspects of information retrieval* (pp. 133–146). Amsterdam/NewYork: Elsevier Science Publishers.

Moravcsik. (1988). The coverage of science in the Third World: the 'Philadelphia program'. In L. Egghe & R. Rousseau (Eds.), *Informetrics 87/88 : selected proceedings of the First International Conference on Bibliometrics and theoretical aspects of information retrieval* (pp. 147–155). Amsterdam: Elsevier.

Mori, Y. (2006). *Electronique pour le traitement du signal. Théorie de l'information et du codage: signal analogique, signal numérique et applications en télécommunications* (Vol. 5). Paris: Lavoisier.

Mouton, J. (2007). *Study on national research systems: a meta-review: regional report on sub saharan Africa*. Paris: UNESCO. Retrieved from http://unesdoc.unesco.org/images/0015/001577/157797e.pdf

Mouton, J., & Waast, R. (2008). *Global synthesis report: study on national research systems: a meta-review* (p. 149). Paris: UNESCO.

Mouton, J., & Waast, R. (2009). Comparative study on national research systems: Findings and lessons. In V. Lynn Meek, U. Teichler, & M.-L. Kearney (Eds.), *Higher Education, Research and Innovation: Changing Dynamics: Report on the UNESCO Forum on Higher Education, Research and Knowledge 2001-2009* (pp. 147–170). Kassel: UNESCO.

Mueller, P. (2006). Exploring the knowledge filter: How entrepreneurship and university–industry relationships drive economic growth. *Research Policy*, *35*(10), 1499–1508. http://doi.org/10.1016/j.respol.2006.09.023

Mugabe, J. O. (2011). *Science, technology and innovation in Africa's regional integration: from rhetoric to practice*. Kampala: Advocates Coalition for Development and Environment.

Nacke, O. (1979). Informetrie: eine neuer name für eine neue disziplin. *Nachr Dok*, *30*, 219–226.

NEPAD Planning and Coordinating Agency. (2014). *African innovation outlook II*. Pretoria: NEPAD Planning and Coordinating Agency.

NEPAD Planning and Coordination Agency. (2010). *African innovation outlook 2010*. Pretoria: NEPAD Planning and Coordination Agency.

Nowotny, H., Scott, P., & Gibbons, M. (2003). `Mode 2' Revisited: The New Production of Knowledge. *Minerva*, *41*(3), 179–194. http://doi.org/10.1023/A:1025505528250

Nwagwu, W. E. (2008). The Nigerian university and the triple helix model of innovation systems: adjusting the wellhead. *Technology Analysis & Strategic Management*, *20*(6), 683–696. http://doi.org/10.1080/09537320802426374

N'Zué, F. F. (2014). *Formulating a regional policy for energy and technology/innovation: what role for taxation?* Praia/Bonn: West Africa Institute - Center for European Integration Studies.

OECD. (1996). *The knowledge-based economy* (No. OCDE/GD(96)102) (p. 46). Paris: OECD.

OECD. (1997). *National innovation systems*. Paris: OECD.

OECD. (1999). *The knowledge-based economy: a set of facts and figures*. Paris: OECD.

OECD. (2002a). *Dynamising national innovation systems*. Paris: OECD.

OECD. (2002b). *Frascati manual: proposed standard practice for surveys on research and experimental development* (6th ed). Paris: OECD Publishing.

OECD. (2007). *Revised field of science and technology (FOS) classification in the Frascati manual* (No. DSTI/EAS/STP/NESTI(2006)19/Final) (p. 12 p.). Paris: OECD.

OECD. (2009). *OECD reviews of innovation policy: Korea*. Paris: OECD Publishing.

OECD. (2010). *Measuring innovation: a new perspective*. Paris: OECD.

OECD. (2013). *OECD Science, Technology and Industry Scoreboard 2013: innovation for growth*. Paris: OECD Publishing. Retrieved from http://dx.doi.org/10.1787/sti_scoreboard-2013-en

OECD. (2014a). Gross domestic spending on R&D (indicator). Retrieved from http://dx.doi.org/10.1787/d8b068b4-en

OECD. (2014b). Researchers (indicator). Retrieved from http://dx.doi.org/10.1787/20ddfb0f-en

OECD. (2015a). Gross domestic product (GDP) (indicator). OECD. Retrieved from doi: 10.1787/dc2f7aec-en

OECD. (2015b). Multifactor productivity (indicator). OECD. Retrieved from doi: 10.1787/a40c5025-en

OECD, & EUROSTAT. (2005). *Oslo manual: guidelines for collecting and interpreting innovation data* (3rd ed.). Paris: Organisation for Economic Co-operation and Development - Statistical Office of the European Communities.

OECD, & National Science Foundation. (1999). High level forum on measuring knowledge in learning economies and societies: programme outline.

Olmeda-Gómez, C., Perianes-Rodríguez, A., & Antonia Ovalle-Perandones, M. A. (2008). Comparative analysis of university-government-enterprise co-authorship networks in three scientific domains in the region of Madrid. *Information Research*, *13*(3). Retrieved from http://informationr.net/ir/13-3/paper352.html

Onyancha, O. B. (2009). South Africa's regional and international research collaboration: an informetric study of participating countries, 1986-2005. In D. N. Ocholla & D. Jacobs (Eds.), *Proceedings of DLIS 10th Annual Conference* (pp. 176–198). KwaDlangezwa: University of Zululand, Department of Information Studies.

Onyancha, O. B., & Maluleka, J. R. (2011a). Eighteen years of research on AIDS: contribution of and collaboration between world regions. *AIDS Research and Human Retroviruses*, *22*(11), 1199–1205.

Onyancha, O. B., & Maluleka, J. R. (2011b). Knowledge production through collaborative research in sub-Saharan Africa: how much do countries contribute to each other's knowledge output and citation impact? *Scientometrics*, *87*(2), 315–336.

Onyancha, O. B., & Ocholla, D. N. (2007). Country-wise collaborations in HIV/AIDS research in Kenya and South Africa, 1980–2005. *LIBRI*, *57*, 239–254.

Organisation Ouest-Africaine de la Santé. (2008). *Plan stratégique 2009-2013*. Bobo-Dioulasso: Organisation Ouest-Africaine de la Santé.

Organization of African Unity. (1980). *Lagos plan of action for the economic development of Africa: 1980-2000*. Adis-Ababa: Organization of African Unity.

Ossenblok, T. L. B., Verleysen, F. T., & Engels, T. C. E. (2012). Patterns of co-authorship in journal articles in the social sciences and humanities (2000-2010). In E. Archambault, Y. Gingras, & V. Larivière (Eds.), *Proceedings of STI 2012 Montréal* (Vol. 2, pp. 640–650). Montréal: Science-Metrix; Observatoire des Sciences et Technologies.

Ossenblok, T. L. B., Verleysen, F. T., & Engels, T. C. E. (2014). Coauthorship of journal articles and book chapters in the social sciences and humanities (2000–2010). *Journal of the Association for Information Science and Technology*, *65*(5), 882–897. http://doi.org/10.1002/asi.23015

Oti-Boateng, P. (2010). *Mission report Accra, Ghana, 27th September -1st October, 2010* (p. 7). Nairobi: UNESCO. Retrieved from http://www.unesco.org/fileadmin/MULTIMEDIA/FIELD/Nairobi/pdf/Mission%20report-Accra%20sept%202010.docx

Otlet, P. (1934). *Traité de documentation: le livre sur le livre: théorie et pratique*. Bruxelles: Editions Mundaneum.

Page, S., Bilal, S., & Overseas Development Institute. (2001). *Regional integration in Western Africa* (p. 53). Ministry of Foreign Affairs, the Netherlands.

Park, H. W., Hong, H. D., & Leydesdorff, L. (2005). A Comparison of the Knowledge-based Innovation Systems in the Economies of South Korea and the Netherlands using Triple Helix Indicators. *Scientometrics*, *65*(1), 3–27.

Park, H. W., & Leydesdorff, L. (2010). Longitudinal trends in networks of university–industry–government relations in South Korea: The role of programmatic incentives. *Research Policy*, *2009*(6), 640–649.

Persson, O. (2013). H-index on everything. *ISSI Newsletter*, *9*(1), 5.

Ponomariov, B., & Toivanen, H. (2014). Knowledge flows and bases in emerging economy innovation systems: Brazilian research 2005–2009. *Research Policy*, *43*(3), 588–596. http://doi.org/10.1016/j.respol.2013.09.002

Pouris, A. (1989). A scientometric assessment of agricultural research in South Africa. *Scientometrics*, *17*(1989), 401–413.

Pouris, A. (1991). Identifying areas of strength in South African technology. *Scientometrics*, *21*, 23–35.

Pouris, A. (2010). A scientometric assessment of the Southern Africa Development Community: science in the tip of Africa. *Scientometrics*, *85*, 145–154.

Pouris, A., & Pouris, A. (2009). The state of science and technology in Africa (2000-2004): a scientometric assessment. *Scientometrics*, *79*, 297–309.

Priem, J., & Hemminger, B. H. (2010). Scientometrics 2.0: New metrics of scholarly impact on the social Web. *First Monday*, *15*(7). Retrieved from http://firstmonday.org/ojs/index.php/fm/article/view/2874/2570

Priem, J., Taraborelli, D., Groth, P., & Neylon, C. (2010, October 26). Altmetrics: a manifesto. Retrieved from http://altmetrics.org/manifesto/

Pritchard, A. (1969). Statistical bibliography or bibliometrics ? *Journal of Documentation*, *25*(4), 348–349.

R Development Core Team. (2014). *R: a language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing. Retrieved from http://www.r-project.org

Ranga, L. M., Debackere, K., & Tunzelmann, N. (2003). Entrepreneurial universities and the dynamics of academic knowledge production: a case study of basic vs. applied research in Belgium. *Scientometrics*, *58*, 301–320.

Rousseau, R. (2009). Informetrics. *Library and Information Service*, *53*(12), 5–7 (+29).

Rousseau, R. (2014). Library science: forgotten founder of bibliometrics. *Nature*, *510*(7504), 218–218.

Rousseau, R., & Ye, Y. F. (2013). A multi-metric approach for research evaluation. *Chinese Science Bulletin*, *58*(26), 3288–3290. http://doi.org/10.1007/s11434-013-5939-3

Saad, M., & Zawdie, G. (2011). *Theory and Practice of Triple Helix Model in Developing Countries: Issues and Challenges*. Taylor & Francis.

Schwab, K., & Sala-i-Martín, X. (2014). *The global competitiveness report 2014–2015* (Full data edition). Geneva: World Economic Forum. Retrieved from http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport_2014-15.pdf

SCImago. (2007). SJR — SCImago Journal & Country Rank. SCImago. Retrieved from http://www.scimagojr.com

Şerbănică, C. (2011). Knowledge circulation between universities, public research organizations and business in the EU 27 : drivers, barriers, actions to be put forward. *European Journal of Interdisciplinary Studies*, *3*(2), 43–54.

Sesay, A., & Omotosho, M. (2011). The politics of regional integration in West Africa. *WACSERIES*, *2*(2), 1–36.

Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, *27*(3), 379-423-656.

Shannon, C. E., & Weaver, W. (1949). *The mathematical theory of communication*. Urbana: University of Illinois.

Shin, J. C., Lee, S. J., & Kim, Y. (2012). Knowledge-based innovation and collaboration: a triple-helix approach in Saudi Arabia. *Scientometrics*, *90*(1), 311–326. http://doi.org/10.1007/s11192-011-0518-3

Shinn, T. (2002). The triple helix and new production of knowledge prepackaged thinking on science and technology. *Social Studies of Science*, *32*(4), 599–614. http://doi.org/10.1177/0306312702032004004

Ssebuwufu, J., Ludwick, T., & Béland, M. (2012). *Strengthening university-industry linkages in Africa: a study on institutional capacities and gaps*. Accra: Association of African Universities - Association of universities and Colleges of Canada. Retrieved from http://www.aucc.ca/wp-content/uploads/2011/07/aau-case-study-university-industry-linkages-africa.pdf

Stock, W. G., & Weber, S. (2006). Facets of informetrics. *Information Retrieval and Documentation*, *57*(8), 385–389.

Subramanyam, K. (1983). Bibliometric studies of research collaboration: a review. *Journal of Information Science*, (6), 35.

Suh, J., Chen, D. H. C., Korea Development Institute, & The World Bank Institute (Eds.). (2007). *Korea as a knowledge economy: evolutionary process and lessons learned*. Washington DC: The World Bank.

Tague-Sutcliffe, J. (1992). An introduction to informetrics. *Information Processing & Management*, *28*(1), 1–3.

Taylor, S. (2004). Knowledge circulation: the 'triple helix' concept applied in South Africa. *Industry and Higher Education*, *18*(5), 329–334.

Theil, H. (1972). *Statistical decomposition analysis: with applications in the social and administrative sciences*. Amsterdam/NewYork: North-Holland Publishing Company.

Thomson Reuters. (2010). OECD Classification — Web of Science subject headings. Thomson Reuters. Thomson Reuters. Retrieved from http://incites.isiknowledge.com/common/help/h_field_category_oecd_wos.html

Thomson Reuters. (2011). *Journal Citation Report: Science edition*. Thomson Reuters.

Tijssen, R. J. W. (2007). Africa's contribution to the worldwide research literature: new analytical perspectives, trends and performance indicators. *Scientometrics*, *71*(2), 303–327.

Toivanen, H., & Ponomariov, B. (2011). African regional innovations systems: bibliometric analysis of research collaboration patterns 2005-2009. *Scientometrics*, *88*(2), 471–493.

Touré, O. Z. (2014). *La CEDEAO et l'UEMOA: deux organisations concurrentes pour une Intégration Régionale en Afrique de l'Ouest*. Praia: West Africa Institute.

Transparency International. (2014). *Corruption perception index 2014*. Berlin: Transparency International. Retrieved from http://files.transparency.org/content/download/1856/12434/file/2014_CPIBrochure_EN.pdf

UNDP. (2005). *International cooperation at a crossroads: aids, trade and security in a unequal world*. New York: United Nations Development Programme.

UNDP. (2013). *The rise of the south: human progress in a diverse world*. New York: United Nations Development Programme. Retrieved from http://hdr.undp.org/sites/default/files/reports/14/hdr2013_en_complete.pdf

UNDP. (2014). *Sustaining human progress: reducing vulnerabilities and building resilience*. New York: United Nations Development Programme.

UNESCO. (1974). *National science policies in Africa : situation and future outlook - Politiques scientifiques nationales en Afrique: situation et perspectives*. Paris: UNESCO. Retrieved from http://unesdoc.unesco.org/images/0000/000069/006958mo.pdf

UNESCO. (1986). *Comparative study on the national science and technology policy-making bodies in the countries of West Africa*. Paris: UNESCO. Retrieved from http://unesdoc.unesco.org/images/0007/000712/071225eo.pdf

UNESCO. (1989a). *Mini-micro CDS/ISIS: manuel de référence: version 2.3*. Paris: UNESCO.

UNESCO. (1989b). *Mini-micro CDS/ISIS: Pascal CDS/ISIS*. Paris: UNESCO.

UNESCO. (2010a). Globalisation. In *Teaching and learning for a sustainable future: a multimedia teacher education programme*. Paris: UNESCO. Retrieved from www.unesco.org/education/tlsf/mods/theme_c/mod18.html

UNESCO. (2010b). *UNESCO science report: the Current Status of Science around the World*. Paris: UNESCO.

UNESCO. (2015). *UNESCO science report: toward 2030*. Paris: UNESCO.

UNESCO Institute of Statistics. (2005). What do bibliometrics indicators tell us about world scientific output? *Bulletin on Science and Technology Statistics*, (2), 1–6.

United Nations Economic Commission for Africa. (2013). *African science, technology and innovation review 2013*. Nairobi: UNECA.

United Nations Economic Commission for Europe. (2002). *Towards a knowledge-based economy: final report*. New York and Geneva: United Nations.

United Nations Population Fund. (2015). *State of world population 2015: Shelter from the storm: a transformative agenda for women and girls in a crisis-prone world*. New York: United Nations Population Fund.

United States Energy Information Administration. (2016). International energy statistics: electricity. United States Energy Information Administration. Retrieved from http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=2&pid=2&aid=12

Urama, K. C., Ozor, N., Kane, O., & Hassan, M. (2010). Sub-Saharian Africa. In L. Brito & S. Schneegans (Eds.), *UNESCO Science report 2010: the current status of Science around the World* (pp. 278–321). Paris: UNESCO.

Uranga, M. G., Kerexeta, G. E., & Campas-Velasco, J. (2007). The dynamics of commercialization of scientific knowledge in biotechnology and nanotechnology. *European Planning Studies*, *15*(9), 1199–1214.

Van Looy, B., Magerman, T., & Debackere, K. (2007). Developing technology in the vicinity of science: an examination of the relationship between science intensity (of patents) and technological productivity within the field of biotechnology. *Scientometrics*, *70*(2), 441–458.

von Bertalanffy, L. (1973). *Théorie générale des systèmes*. Paris: Dunod.

Waast, R. (2002). *The state of science in Africa: an overview*. Paris: France. Ministère des affaires étrangères.

Wagner, C. S. (2006). International collaboration in science and technology: promises and pitfalls. In L. Box & R. Engelhard (Eds.), *Science and Technology Policy for Development, Dialogues at the Interface*. London: Anthem Press. Retrieved from http://www.anthempress.com/product_info.php?cPath=96&products_id=274&osCsid=icd69j s77l634iqvoni0t6vk67

Wagner, C. S., Park, H. W., & Leydesdorff, L. (2015). The continuing growth of global cooperation networks in research: a conundrum for national governments. *PloS One*, *10*(7), 1–15. http://doi.org/10.1371/journal.pone.0131816

Waltman, L., Tijssen, R. J. W., & Van Eck, N. J. (2011). Globalisation of science in kilometres. Journal of Informetrics. *Journal of Informetrics*, *54*(4), 574–582. http://doi.org/doi:10.1016/j.joi.2011.05.003

Waltman, L., & van Eck, N. J. (2012). The inconsistency of the h-index. *Journal of the American Society for Information Science and Technology*, *63*(2), 406–415. http://doi.org/10.1002/asi.21678

World Bank. (1999). *World development report: knowledge for development: 1988/1989*. Oxford: Oxford University Press.

World Bank. (2014a). *Doing business 2015: going beyond efficiency: regional profile 2015: Economic Community of West African States (ECOWAS)* (12th ed.). Washington DC: The World Bank.

World Bank. (2014b). World development indicators. Retrieved from http://data.worldbank.org/products/wdi

World Bank. (2015). *Doing business 2015: going beyond efficiency: comparing business regulations for domestic firms in 189 economies* (12th edition). Washington DC: World Bank.

World Health Organisation. (2015). *World health statistics 2015*. Geneva: World Health Organisation.

Ye, Y. F., Yu, S. S., & Leydesdorff, L. (2013). The Triple Helix of university-industry-government relations at the country level, and its dynamic evolution under the pressures of globalization. *Journal of the American Society for Information Science and Technology*, *64*, 2317–2325.

Yeung, R. W. (2001). *A first course in information theory*. Boston: Kluwer Academic Publishers. Retrieved from http://iest2.ie.cuhk.edu.hk/~whyeung/tempo/main.pdf

Yeung, R. W. (2008). *Information theory and network coding*. New York: Springer.

Yuret, T. (2016). International trade in ideas. *Scientometrics*, 1–18. http://doi.org/10.1007/s11192-016-1883-8

Zitt, M., Bassecoulard, E., & Okubo, Y. (2000). Shadows of the past in international cooperation: collaboration profiles of the top five producers of science. *Scientometrics*, *47*(3), 627–657.

12. Papers produced while writing this thesis

Conference papers: 5 – Brief articles: 3 – Full articles: 11

1. Mêgnigbêto, E. (2012). Scientific publishing in West Africa: a comparison of Benin with Ghana and Senegal. In *Proceedings of STI 2012* (Vol. 2, pp. 589–600). Montréal: Science Metrix; Observatoire des sciences et des Technologies.

2. Mêgnigbêto, E & Houzanmè, U. T. (2012). Radioscopie de la recherche scientifique au Bénin: une étude bibliométrique à travers Web of Science. *Revue Perspectives et Sociétés*, *3*(1), 180–206.

3. Mêgnigbêto, E. (2013a). International collaboration in scientific publishing: the case of West Africa (2001-2010). *Scientometrics*, *96*(3), 761–783. http://doi.org/10.1007/s11192-013-0963-2

4. Mêgnigbêto, E. (2013b). Intra-regional collaboration in the West African science. In Université d'Abomey-Calavi (Ed.), *IV Colloque de l'Université d'Abomey-Calavi*. Abomey-Calavi.

5. Mêgnigbêto, E. (2013c). Scientific publishing in Benin as seen from Scopus. *Scientometrics*, *94*(3), 911–928. http://doi.org/10.1007/s11192-012-0843-1

6. Mêgnigbêto, E. (2013d). Scientific publishing in West Africa: a comparison with BRICS. In S. Hinze & A. Lottmann (Eds.), *Translation twists and turns: science as a socio-economic endeavor: proceedings of STI 2013* (pp. 557–560). Berlin: Institute for Research Information and Quality Assurance - European Network of Indicators Designers.

7. Mêgnigbêto, E. (2013e). Scientific publishing in West Africa: comparing Benin with Ghana and Senegal. *Scientometrics*, *95*(3), 1113–1139. http://doi.org/10.1007/s11192-012-0948-6

8. Mêgnigbêto, E. (2013f). Scientific research in West Africa: a global view (2001-2010). *ISSI Newsletter*, *9*(1), 6–11.

9. Mêgnigbêto, E. (2013g). Triple Helix of university-industry-government relationships in West Africa. *Journal of Scientometric Research*, *2*(3), 54–62. http://doi.org/10.4103/2320-0057.135413

10. Mêgnigbêto, E. (2014a). Efficiency, unused capacity and transmission power as indicators of the Triple Helix of university-industry-government relationships. *Journal of Informetrics*, *8*(1), 284–294. http://doi.org/10.1016/j.joi.2013.12.009

11. Mêgnigbêto, E. (2014b). Information flow between West African Triple Helix actors. *ISSI Newsletter*, *10*(1), 14–20.

12. Mêgnigbêto, E. (2014c). Information flow within West African innovation systems. *Triple Helix: A Journal of University-Industry-Government Innovation and Entrepreneurship*, *1*(1), 1–13. http://doi.org/10.1186/s40604-014-0005-y

13. Mêgnigbêto, E. (2014d). La collaboration en matière de recherche scientifique et technique au Bénin : 2005-2009. *Revue Canadiennes de Sciences de L'information et de Bibliothéconomie - Canadian Journal for Information and Library Science*, *38*(3), 188–204.

14. Mêgnigbêto, E. (2014e). Transmission power as an indicator of innovation: Is there any relations between transmission power and economic performance ? Presented at the Journées scientifiques internationales de Lomé, Lomé.

15. Mêgnigbêto, E. (2014f). Transmission power in some particular cases of bi- or tri-dimensional complex systems. *Journal of Scientometric Research*, *3*(1), 37–45. http://doi.org/10.4103/2320-0057.143704

16. Mêgnigbêto, E. (2015a). Effect of international collaboration on knowledge flow within an innovation system: a Triple Helix approach. *Triple Helix: A Journal of University-Industry-Government Innovation and Entrepreneurship*, *2*(1). http://doi.org/10.1186/s40604-015-0027-0

17. Mêgnigbêto, E. (2015b). Evaluation de l'économie du savoir au niveau de la région ouest-africaine : une approche basée sur le modèle de la Triple Hélice. Presented at the Vème Colloque de l'Université d'Abomey-Calavi, Abomey-Calavi: Université d'Abomey-Calavi.

18. Mêgnigbêto, E. (2015c). Profiles of six OECD countries with regard to mutual information and transmission power. *ISSI Newsletter*, *11*(1), 16–23.

19. Mêgnigbêto, E. (under review). Correlation between transmission power and some indicators used to measure the knowledge-based economy: case of six OECD countries. *Journal of the knowledge economy*

13. Appendices

Appendix 1: Source of the CDS/ISIS Pascal programme for producing a text file on the research collaboration at a country level for analyses with the Pajek software

```
program country_net;

{builds a text file on the research collaboration among countries to be analysed with the Pajek
software}

var rc, i, j, max : real;
prefixe term, sysv : string;
terms : array[1..1000] of string;

Begin
open('db');
assign('out', 'country.net');
prefix:='CO=';
term:=prefix;
rc:=find(term);
i:=0; j:=0; rc:=0;
while (term <> '') and (substr(term,1,size(prefix))=prefix) do
        begin
                i:=i+1;
                terms[i]:=substr(term,size(prefix)+1,size(term));
                term:=nxtterm;
        end;
max:=i;
writeln(out, '*Vertices   ', max:1);
for i:=1 to max do writeln(out, '  ', i:1, ' "'|terms[i]|'"');
writeln(out, '*Edges');
sysv:=sysvars('00000');
for i:=1 to max do
        begin
  for j:=1 to max do
                        begin
                                if j > i then
                                begin
                                rc:=search(prefix|terms[i]|' * '|prefix|terms[j]);
                                rc:=setpos(0,0);
                                if rc<>0 then writeln(out, i:1, ' ', j:1, ' ', rc:1);
                                end
end;
        flush;
end;
end.
```

Appendix 2. List of special issues of journals on the Triple Helix

(Update of the list provided by Mitra & Edmondson, 2015, pp. 147–148)

Year	Journal	Volume	Issue
1997	Science and public policy	24	1
1998	Minerva	36	3
1998	Industry and higher education	12	4
1998	Science and public policy	25	6
1999	Journal of technology transfer	24	2-3
2000	Reseach policy	29	2
2000	Science and public policy	27	4
2003	Science, technology and human values	28	1
2008	International jounral of technology management and sustainable development	7	3
2003	Scientometrics	58	2
2003	Science and public policy	30	4
2005	Technology analysis ans qtrategic management	17	1
2006	Reseach policy	35	10
2007	Scientometrics	70	2
2008	Science and public policy	35	9
2010	Industry and higher education	24	3
2010	Journal of technology management and innovation	5	1
2010	Technlog analysis and strategic management	22	7
2011	Science and public policy	38	1
2012	Scientometrics	90	1
2013	Industry and higher education	27	4
2013	Social Science information	52	4
2014	Scientometrics	99	1

Appendix 3: Upper and lower bounds to the mutual information in three dimensions

The formula of the three-dimensional mutual information is:

$$\mathrm{T_{XYZ}} = \mathrm{H_X} + \mathrm{H_Y} + \mathrm{H_Z} - \mathrm{H_{XY}} - \mathrm{H_{XZ}} - \mathrm{H_{YZ}} + \mathrm{H_{XYZ}} \quad (13\text{-}1)$$

The terms of Equation (13-1) can be grouped as follows:

$$\mathrm{T_{XYZ}} = (\mathrm{H_X} - \mathrm{H_{XY}}) + (\mathrm{H_Y} - \mathrm{H_{YZ}}) + (\mathrm{H_Z} - \mathrm{H_{XZ}}) + \mathrm{H_{XYZ}} \quad (13\text{-}2)$$

or

$$\mathrm{T_{XYZ}} = (\mathrm{H_X} - \mathrm{H_{XZ}}) + (\mathrm{H_Y} - \mathrm{H_{XY}}) + (\mathrm{H_Z} - \mathrm{H_{YZ}}) + \mathrm{H_{XYZ}} \quad (13\text{-}3)$$

Equations (13–2) and (13–3) are equivalent (See Appendix 13)

Equation (13–2) leads to

$$\mathrm{T_{XYZ}} = -(\mathrm{H_{XY}} - \mathrm{H_X}) - (\mathrm{H_{YZ}} - \mathrm{H_Y}) - (\mathrm{H_{XZ}} - \mathrm{H_Z}) + \mathrm{H_{XYZ}} \quad (13\text{-}4)$$

The system's entropy minus one variable's entropy gives the second variable conditional entropy. The formula is (Shannon, 1948)

$$\mathrm{H_{XY}} - \mathrm{H_X} = \mathrm{H}_{\mathrm{Y}|X} \quad (13\text{-}5)$$

Similarly,

$$\mathrm{H_{YZ}} - \mathrm{H}_Y = \mathrm{H}_{Z|Y} \quad (13\text{-}6)$$

and

$$\mathrm{H}_{\mathrm{X}Z} - \mathrm{H}_Z = \mathrm{H}_{X|Z} \quad (13\text{-}7)$$

Thus, we can write Equation (13–4) as follows:

$$\mathrm{T_{XYZ}} = -\mathrm{H_{Y|X}} - \mathrm{H_{Z|Y}} - \mathrm{H}_{\mathrm{X}|Z} + \mathrm{H_{XYZ}} \quad (13\text{-}8)$$

The bilateral conditional entropies $H_{X|Z}$, $H_{Y|X}$ and $H_{Z|Y}$ are all positive; therefore, their opposites$-H_{X|Z}$, $-H_{Y|X}$ and $-H_{Z|Y}$ are all negative, so is the quantity $-H_{X|Z}- H_{Y|X}-H_{Z|Y}$. Because H_{XYZ} is positive, it appears like the upper bound to T_{XYZ} in Equation (13-6). Furthermore, the bilateral conditional transmissions may be null. So, we can write:

$$\mathrm{T_{XYZ}} \leq \mathrm{H_{XYZ}} \quad (13\text{-}9)$$

Mutual information and one variable's entropy and the same variable conditional entropy are related (cf. Yeung, 2001, 2008):

$$\mathrm{H_{X|Y}} + \mathrm{T_{XY}} = \mathrm{H_X} \quad (13\text{-}10)$$

Thus,

$$H_{X|Y} = H_X - T_{XY} \quad (13\text{-}11)$$

Equation (13-11) allows writing that

$$H_{X|Y} \leq H_X \quad (13\text{-}12)$$

Therefore,

$$H_{Y|X} \leq H_Y \quad (13\text{-}13)$$

$$H_{Z|Y} \leq H_Z \quad (13\text{-}14)$$

$$H_{X|Z} \leq H_X \quad (13\text{-}15)$$

Thus, the sum of Equations (13-13), (13-14) and (13-15) gives:

$$H_{Y|X} + H_{Z|Y} + H_{X|Z} \leq H_X + H_Y + H_Z \quad (13\text{-}16)$$

The negation of Equation (13-16) gives:

$$-H_X - H_Y - H_Z \leq -H_{Y|X} - H_{Z|Y} - H_{X|Z} \quad (13\text{-}17)$$

Adding HXYZ to the right and left terms of Equation (13-17) gives:

$$-H_X - H_Y - H_Z + H_{XYZ} \leq -H_{Y|X} - H_{Z|Y} - H_{X|Z} + H_{XYZ} \quad (13\text{-}18)$$

The right term of Equation (13-18) represents TXYZ (cf. Equation (13-8)). It comes that:

$$-H_X - H_Y - H_Z + H_{XYZ} \leq T_{XYZ} \quad (13\text{-}19)$$

And finally, we can write, from Equations (13-9) and (13-19):

$$H_{XYZ} - H_X - H_Y - H_Z \leq T_{XYZ} \leq H_{XYZ} \quad (13\text{-}20)$$

In conclusion, the lower bound to the three dimensional transmission is the system’s entropy (or the joint entropy of the three variables) minus each of the three marginal entropies and the upper bound to the three dimensional transmission is the system's entropy.

.

Appendix 4 Computing sectorial, bi or tri-dimensional entropies and transmissions

Let us consider a University-Industry-Government system where the outputs are as follows: University (U) alone: 125 units, Industry (I) alone: 25 units, Government (G) alone: 75 units, University and Industry (UI): 20 units, University and Government (UG): 50 units, Industry and Government (IG): 15 units, University, Industry and Government (UIG): 10 units.

Case 1: The two-dimensional system S = (U, I)

Because data are given for a trilateral system, we need, first, to proceed to some corrections for determining the right output of U alone, I alone and the joint output of U and I in the bilateral system S = (U,I). For the correction purpose, to avoid confusion between terms, we index output with the system's dimension; so that, U_2 means U in a two-dimensional system and I_3 means I in a three-dimensional one. Referring to Figure 6-2, we can write: $U_2 = U_3 + UG_3$, $I_2 = I_3 + IG_3$ and $UI_2 = UI_3 + UIG_3$. Therefore, $U_2 = 125 + 50 = 175$ units, $I_2 = 25 + 15 = 40$ units and $UI_2 = 20 + 10 = 30$ units. The total output of the system S = (U, I) is then $T = U_2 + I_2 + UI_2 = 245$ units.

Returning to the standard notation, we can write for the two-dimensional system that U = 175 units, I = 40 units and UI = 30 units. Therefore, the probability that U only produces is p(U = 1, I = 0) = $\frac{175}{245}$; the probability that I only produces is p(I = 1, U = 0) = $\frac{40}{245}$; the probability that U and I produce jointly is p(U = 1, I = 1) =$\frac{30}{245}$. In this particular case, the probability that neither U nor I produce is p(U=0, I=0) = 0. We can check that p(U=1, I=0) + p(I=1, U=0) + p(U = 1, I = 1) + p(U=0, I=0) = $\frac{40}{245} + \frac{40}{245} + \frac{30}{245} + 0 = \frac{245}{245} = 1$. We derive the entropy of the system S = (U, I) using the formula in Equation (6-2) which leads to H_S = 1.145 bits. Then Table 13-1 follows:

Table 13-1. Distribution of probability in the bi-dimensional S = (U, I) system

I U	0	1	p(U)
0	0	$\frac{40}{245}$	$\frac{40}{245}$
1	$\frac{175}{245}$	$\frac{30}{245}$	$\frac{205}{245}$
p(I)	$\frac{175}{245}$	$\frac{70}{245}$	1

The probability that U produces, whether I produces or not is p(U.) = $\frac{205}{245}$ and the probability that U doesn't produce is $\frac{40}{245}$ (Table 13-1, Colum p(U)); the probability that I produces whether U produces or not is $p(I) = \frac{40}{245}$ and the probability that I doesn't produce is $\frac{175}{245}$ (Table 13-1, Row p(I)). Therefore, applying the formula in Equation (6-2), the entropies of U and I are respectively: H_U = 0.863 bits and H_I = 0.642 bits. Then, follows the bilateral transmission using Equation (6-4). We summarize data in Table 13-2.

Table 13-2. Data summary

Indicator	Value (units)	Indicator	Value (bits)	Indicator	Value
U (only)	175	HU	0.863	Efficiency (η)	0.722
I (only)	40	HI	0.642	Unused capacity	0.44
UI	30	HUI	1.145	Relative unused capacity (ρ)	0.278
Total	245	TUI	0.361	Transmission power (τ)	0.315

Case 2: The three-dimensional system S = (U, I, G)

Similarly as in the case of two-dimensional system, we can compute the probabilities and the contributions to the system's entropy as shown in Table 13-3. We get H_{UIG} = 2.339 bits.

Table 13-3. Sectorial probabilities and contribution to the three-dimensional entropy

	Output	Probability (pi)	pi * $\log_2$pi
U (only)	125	0.39	0.53
I (only)	25	0.08	0.29
G (only)	75	0.23	0.49
UI	20	0.06	0.25
UG	50	0.16	0.42
IG	15	0.05	0.21
UIG	10	0.03	0.16
Total	320	1.00	2.339

We crossed each two-dimensional distribution with the third distribution in order to compute sectorial and two-dimensional entropies (Table 13-4, Table 13-5 andTable 13-6). In these tables, the couple (00) means that the first actor doesn't produce, the second neither; (10) means that the first produces but the second doesn't. Table 13-4 summarizes sectorial entropies, two-dimensional, system's entropies and transmissions.

Table 13-4. Bilateral UI and sectorial G distribution of probability

UI G	(00)	(01)	(10)	(11)	p(G)
0	0	0.078	0.391	0.063	0.531
1	0.234	0.047	0.156	0.031	0.469
p(UI)	0.234	0.125	0.547	0.094	1.000

Table 13-5. Bilateral UG and sectorial I distribution of probability

UG I	(00)	(01)	(10)	(11)	p(I)
0	0	0.234	0.391	0.156	0.781
1	0.078	0.047	0.063	0.031	0.219
p(UG)	0.078	0.281	0.453	0.188	

Table 13-6. Bilateral IG and sectorial U distribution of probability

IG U	(00)	(01)	(10)	(11)	p(U)
0	0	0.234	0.078	0.047	0.359
1	0.391	0.156	0.063	0.031	0.641
p(IG)	0.391	0.391	0.141	0.078	

Table 13-7. Sectorial, bilateral and trilateral entropies, transmissions and efficiency, unused capacity and transmission power of the system.

Indicator	Value	Indicator	Value
H_{UIG}	2.339 bits	T_{IG}	0.01 bits
H_U	0.942 bits	T_{UIG}	– 0.143 bits
H_I	0.758 bits	Efficiency (η)	0.833
H_G	0.997 bits	Unused capacity	0.468
H_{UI}	1.662 bits	Relative unused capacity (ρ)	0.167
H_{UG}	1.772 bits	Minimum T_{UIG}	– 0.358
H_{IG}	1.745 bits	Maximum T_{UIG}	2.339
T_{UI}	0.038 bits	$H_{max} = \log_2 7$	2.807
T_{UG}	0.167 bits	Transmission power $\tau = \tau_1$	0.398

Appendix 5 Conditions for the conditional entropies are null in a two-dimensional system

Let us consider two random variables X and Y each with the alphabet A = {0, 1}. The joint probability distribution of X and Y and the conditional probability distribution are given in and respectively.

Table 13-8. Joint probability distribution of X and Y

Y / X	0	1	p(X)
0	p(0,0)	p(0,1)	p(X = 0) =p(0,0)+p(0,1)
1	P(1, 0)	p(1,1)	p(X = 1) = p(1,0) + p(1,1)
p(Y)	p(Y = 0) = p(0,0) + p(1,0)	p(Y = 1) = p(0, 1) + p(1,1)	1

Table 13-9.Conditional probability distribution of X on Y (X|Y)

Y / X	0	1
0	$\frac{p(0,0)}{\mathrm{p}(0,0) + \mathrm{p}(1,0)}$	$\frac{p(0,1)}{\mathrm{p}(0,1) + \mathrm{p}(1,1)}$
1	$\frac{p(1,0)}{\mathrm{p}(0,0) + \mathrm{p}(1,0)}$	$\frac{p(1,1)}{\mathrm{p}(0,1) + \mathrm{p}(1,1)}$

By definition, the conditional entropy $H_{X|Y}$ is (Yeung, 2001, p. 12, 2008, p. 14):

$$\mathrm{H}_{\mathrm{X|Y}} = \sum_{\mathrm{x,y}} \mathrm{p(x,y)} \times \log_2 \mathrm{p(x|y)} = -\sum_{\mathrm{y}} \mathrm{p(y)} \times \mathrm{H}_{\mathrm{X|Y=y}} \quad (13\text{-}21)$$

Then, from Table 13-9, we can write

$$\mathrm{H}_{\mathrm{X|Y}} = -\frac{\mathrm{p}(0,0)}{\mathrm{p}(0,0)+\mathrm{p}(1,0)}\log_2\frac{\mathrm{p}(0,0)}{\mathrm{p}(0,0)+\mathrm{p}(1,0)} \times \left(\mathrm{p}(0,0)+\mathrm{p}(1,0)\right) - \frac{\mathrm{p}(1,0)}{\mathrm{p}(0,0)+\mathrm{p}(1,0)}\log_2\frac{\mathrm{p}(1,0)}{\mathrm{p}(0,0)+\mathrm{p}(1,0)} \times \left(\mathrm{p}(0,0)+\mathrm{p}(1,0)\right) - \frac{\mathrm{p}(0,1)}{\mathrm{p}(0,1)+\mathrm{p}(1,1)}\log_2\frac{\mathrm{p}(0,1)}{\mathrm{p}(0,1)+\mathrm{p}(1,1)} \times (\mathrm{p}(0,1)+\mathrm{p}(1,1)) - \frac{\mathrm{p}(1,1)}{\mathrm{p}(0,1)+\mathrm{p}(1,1)}\log_2\frac{\mathrm{p}(1,1)}{\mathrm{p}(0,1)+\mathrm{p}(1,1)} \times (\mathrm{p}(0,1)+\mathrm{p}(1,1)) \quad (13\text{-}22)$$

Because $H_{X|Y}$ is a positive scalar (Yeung, 2001, p. 12, 2008, p. 14), it is null if and only if each of the positive terms that compose it is null. Therefore,

$$\begin{cases} -\frac{p(0,0)}{p(0,0)+p(1,0)}\log_2\frac{p(0,0)}{p(0,0)+p(1,0)} \times \big(p(0,0) + p(1,0)\big) = 0 \\ -\frac{p(1,0)}{p(0,0)+p(1,0)}\log_2\frac{p(1,0)}{p(0,0)+p(1,0)} \times \big(p(0,0) + p(1,0)\big) = 0 \\ -\frac{p(0,1)}{p(0,1)+p(1,1)}\log_2\frac{p(0,1)}{p(0,1)+p(1,1)} \times (p(0,1) + p(1,1)) = 0 \\ -\frac{p(1,1)}{p(0,1)+p(1,1)}\log_2\frac{p(1,1)}{p(0,1)+p(1,1)} \times \big(p(0,1) + p(1,1)\big) = 0 \end{cases} \quad (13\text{-}23)$$

Equation (13-24) becomes:

$$\begin{cases} p(0,0) = 0 \text{ or } p(1,0) = 0 \\ p(0,1) = 0 \text{ or } p(1,1) = 0 \end{cases} \quad (13\text{-}24)$$

In System of equations (13-24), the 'or' is inclusive, so it yields $2^3 = 8$ combinations of the four probabilities p(0, 0), p(0, 1), p(1, 0) and p(1,1). The same combinations are solution of $H_{Y|X}$ under the condition that positions are inverted in the couple in headers of column. The 7 bi-dimensional configurations that satisfy System of equations (13-24) are presented in .

Table 13-10. Solutions of equation $H_{X|Y} = 0$ and $H_{Y1X} = 0$

	(0, 0)	(0, 1)	(1, 0)	(1, 1)
1	0	0	0	0
2	0	0	0	α
3	0	0	α	0
4	0	α	0	0
5	α	0	0	0
6	0	α	α	0
7	α	0	0	α

Note: α indicates any positive non null number.

Appendix 6 Equivalence of systems of equations (6-36) and (6-37)

A variable's entropy minus transmission gives its conditional entropy: $\mathrm{H_X} = \mathrm{H_{X|Y}} + \mathrm{T_{XY}}$. Let us draw successively the expressions of H_X, H_Y and T_{XY}:

$$\mathrm{H_X} = \mathrm{H_{X|Y}} + \mathrm{T_{XY}} \tag{13-25}$$

$$\mathrm{H_Y} = \mathrm{H_{Y|X}} + \mathrm{T_{YZ}} \tag{13-26}$$

$$\mathrm{T_{XY}} = \mathrm{H_X} - \mathrm{H_{X|Y}} \tag{13-27}$$

Replacing Equation (13-27) into Equation (13-26) gives

$$\mathrm{H_Y} = \mathrm{H_{Y|X}} + \mathrm{H_X} - \mathrm{H_{X|Y}} \tag{13-28}$$

Therefore,

$$\mathrm{H_{X|Y}} = \mathrm{H_X} - H_Y + \mathrm{H_{Y|X}} \tag{13-29}$$

$$\mathrm{H_{Y|X}} = \mathrm{H_Y} - H_X + \mathrm{H_{Y|X}} \tag{13-30}$$

Subtracting Equation (13-30) from Equation (13-29) leads to:

$$\mathrm{H_{X|Y}} - \mathrm{H_{Y|X}} = 2(H_X - \mathrm{H}_y) \tag{13-31}$$

Similarly,

$$\mathrm{H_{Y|Z}} - \mathrm{H_{Z|Y}} = 2(H_Y - \mathrm{H_Z}) \tag{13-32}$$

$$\mathrm{H_{Z|X}} - \mathrm{H_{X|Z}} = 2(H_Z - \mathrm{H}_X) \tag{13-33}$$

Summing up Equations (13-31), (13-32) and (13-33) leads to:

$$H_{X|Y} - H_{Y|X} + \mathrm{H_{Y|Z}} - \mathrm{H_{Z|Y}} + H_{Z|X} - \mathrm{H_{X|Z}} = 0 \tag{13-34}$$

which may also be written as follows:

$$(H_{X|Y} + \mathrm{H_{Y|Z}} + H_{Z|X}) - (H_{Y|X} + \mathrm{H_{Z|Y}} + \mathrm{H_{X|Z}}) = 0 \tag{13-35}$$

According to System of equations (6-36), $H_{X|Y} = H_{Y|Z} = H_{Z|X} = 0$; therefore, Equation (13-35) is equivalent to

$$H_{Y|X} + \mathrm{H_{Z|Y}} + \mathrm{H_{X|Z}} = 0. \tag{13-36}$$

Because conditional entropies are necessary positive, Equation (13-36) means that each of its terms is null; therefore, $\mathrm{H_{X|Z}} = 0, \mathrm{H_{Y|X}} = 0$ and $\mathrm{H_{Z|Y}} = 0$ which is the System of equations (6-36). An analogous logical reasoning on System of equations (6-37) results in System of equations (6-37). So, the two are equivalent.

Appendix 7 Conditions for the conditional entropies are null in a three-dimensional system

By considering each of the 8 cases for $H_{X|Y} = 0$, $H_{Y|Z} = 0$ and $H_{Z|X} = 0$ (cf. Appendix 6), we obtain $8^3 = 512$ combinations of which 12 () satisfy each $H_{X|Y} = 0$, $H_{Y|Z} = 0$ and $H_{Z|X} = 0$.

Table 13-11. Solutions of $H_{X|Y} = 0$, $H_{Y|Z} = 0$ and $H_{Z|X} = 0$

	(0,0,0)	(0,0,1)	(0,1,0)	(0,1,1)	(1,0,0)	(1,0,1)	(1,1,0)	(1,1,1)
1	0	0	0	0	0	0	0	0
2	α	0	0	0	0	0	0	0
3	0	α	0	0	0	0	0	0
4	0	0	α	0	0	0	0	0
5	0	0	0	α	0	0	0	0
6	0	0	0	0	α	0	0	0
7	0	0	0	0	0	α	0	0
8	0	0	0	0	0	0	α	0
9	0	0	0	0	0	0	0	α
10	0	0	0	α	α	0	0	0
11	0	0	α	0	0	α	0	0
12	0	α	0	0	0	0	α	0

Note: α indicates any positive non null number.

Appendix 8. Demonstrating how trilateral entropy could be equal to bilateral entropy.

Let us consider a three-dimensional system of university-industry-government relationships S = (U, I, G). Let us suppose that the seven engendered sets' cardinalities are: U = α, G = β, UG = γ, I = δ, (α, β, γ and δ > 0) and UI = IG = UIG = 0. The cardinality of the considered universal set is T = α + β + γ + δ. Therefore, using formula in Equation (), the entropy of the system is

$$\mathrm{H_{UIG}} = -\frac{\alpha}{T}\log_2\frac{\alpha}{T} - \frac{\beta}{T}\log_2\frac{\beta}{T} - \frac{\gamma}{T}\log_2\frac{\gamma}{T} - \frac{\delta}{T}\log_2\frac{\delta}{T}$$

Hereafter, we consider the three two-dimensional systems derived from the three-dimensional one which are university-industry (UI), university-government (UG) and industry-government (IG). We calculate the non-empty sets' cardinality (Table 13-12) using the method indicated in (Mêgnigbêto 2014). Figure 13-1 gives an illustration.

a) Cardinalities in a three dimensional system S = (U, I, G)

b) Cardinalities in a two dimensional (sub-) system S = (U, I) drawn from a three dimensional system S = (U, I, G)

Figure 13-1 Venn diagram of cardinalities in two dimensions S= (U,I) drawn from cardinalities in three dimensions S = (U, I, G).

$\mathrm{H_{UG}}$ can be derived from Table 13-12 (b).

$$\mathrm{H_{UG}} = -\frac{\alpha}{T}\log_2\frac{\alpha}{T} - \frac{\beta}{T}\log_2\frac{\beta}{T} - \frac{\gamma}{T}\log_2\frac{\gamma}{T} - \frac{\delta}{T}\log_2\frac{\delta}{T}$$

which is identically equal to HUIG.

Particularly, when δ = 0 (e.g. the industrial output is null), Table 13-12 (a) and Table 13-12 (c) show that U and I one the one hand and I and G on the other hand are independent. Thus $T_{UI} = T_{IG} = 0$, $H_I = 0$, $H_{UI} = H_U$ and $H_{IG} = H_G$. Therefore, $\mathrm{T_{UIG}} = \mathrm{H_U} + \mathrm{H_I} + \mathrm{H_G} - \mathrm{H_{UI}} - \mathrm{H_{IG}} - \mathrm{H_{UG}} + \mathrm{H_{UIG}} = 0$, which suggests that the three variables are mutually independents and hence pairwise independent (Yeung 2001; Cover and Thomas 2006; Yeung 2008) but Table 13-12 (b) shows that U and G are not.

Table 13-12. Computation of non-empty sub-set of a two dimensional system derived from the tri-dimensional one and probability distributions

Cardinalities in S = (U, I)	:	$O_2 = O_3 + G_3 = 0 + \beta = \beta$	$U_2 = U_3 + UG_3 = \alpha + \gamma$	$I_2 = I_3 + UG_3 = \delta + 0 = \delta$	$UI = UI_3 + UIG_3 = 0 + 0 = 0$
Cardinalities in S = (U, G)	:	$O_2 = O_3 + I_3 = 0 + \delta = \delta$	$U_2 = U_3 + UI_3 = \alpha + 0 = \alpha$	$G_2 = G_3 + IG_3 = \beta + 0 = \beta$	$UG_2 = UG_3 + UIG_3 = \gamma + 0 = \gamma$
Cardinalities in S = (I, G)	:	$O_2 = O_3 + U_3 = 0 + \alpha = \alpha$	$I_2 = I_3 + IU_3 = \delta + 0 = \delta$	$G_2 = G_3 + UG_3 = \beta + \gamma$	$IG_2 = IG_3 + IUG_3 = 0 + 0 = 0$

(a) Probability distribution in S = (U,I)

I U	0	1	p(U)
0	$\frac{\beta}{T}$	$\frac{\delta}{T}$	$\frac{\beta + \gamma}{T}$
1	$\frac{\propto + \gamma}{T}$	0	$\frac{\propto + \gamma}{T}$
p(I)	$\frac{\propto + \beta + \gamma}{T}$	$\frac{\delta}{T}$	1

(b) Probability distribution in S = (U, G)

G U	0	1	p(U)
0	$\frac{\delta}{T}$	$\frac{\beta}{T}$	$\frac{\beta + \delta}{T}$
1	$\frac{\propto}{T}$	$\frac{\gamma}{T}$	$\frac{\alpha + \gamma}{T}$
	$\frac{\alpha + \delta}{T}$	$\frac{\beta + \gamma}{T}$	11

(c) Probability distribution in S = (I, G)

G	0	1	p(G)
0	$\frac{\alpha}{T}$	$\frac{\delta}{T}$	$\frac{\alpha + \delta}{T}$
1	$\frac{\beta + \gamma}{T}$	0	$\frac{\beta + \gamma}{T}$
p(I)	$\frac{\alpha + \beta + \gamma}{T}$	$\frac{\delta}{T}$	1

Appendix 9 Framework for measuring knowledge-based economy

World Bank knowledge economy indicators

Source: The Knowledge Assessment Methodology (KAM) website (www.worldbank.org/kam)

1. Performance
1.1 Average annual GDP growth (%)
1.2 Human Development Index
2. Economic Incentive and Institutional Regime
2.1 Tariff and non-tariff barriers
2.2 Regulatory Quality
2.3 Rule of Law
3. Education and Human Resources
3.1 Adult Literacy rate (%age 15 and above)
3.2 Secondary Enrolment
3.3 Tertiary Enrolment
4. Innovation System
4.1 Researchers in R-D, per million populations
4.2 Patent Applications granted by the USPTO, per million populations
4.3 Scientific and technical journal articles, per million populations
5. Information Infrastructure
5.1 Telephones per 1000 persons, (telephone mainlines + mobile phones)
5.2 Computers per 1000 persons
5.3 Internet Users per 10000 persons

OECD knowledge economy indicators

Source: (OECD, 1999)

1. Knowledge-Based Economy
1.1 Knowledge Investment (education, R&D and software) as % of GDP
1.2 Education of the adult population as % of the population aged 25-64
1.3 R&D expenditure as a percentage of GDP
1.4 Basic research expenditure as a percentage of GDP
1.5 Expenditure of Business R&D in domestic product of industry
1.6 Expenditure of Business R&D in manufacturing
1.7 Share of services in R&D expenditure
1.8 Expenditure on innovation as a share of total sales
1.9 Investment in venture capital as a percentage of GDP
2. Information and Communication Technology

2.1 ICT spending as % of GDP
2.2 PC penetration in households
2.3 Number of internet host per 1000 inhabitants
2.4 Percentage share of ICT industries in GDP
2.5 Share of ICT in patents granted by USPTO
3. Science and Technology Policies
3.1 Publicly funded R&D as % of GDP
3.2 Government R&D expenditure on health-defense-environment
3.3 Government R&D expenditure in total R&D expenditure
3.4 Business R&D expenditure in total R&D expenditure
3.5 Share of Government-Business R&D expenditure financed together
3.6 Tax subsidies rate for R&D
4. Globalization
4.1 Share of foreign affiliates in R&D
4.2 Share of foreign and domestic ownership in total inventions
4.3 Number of international technological alliances
4.4 Percentage of scientific publications with a foreign co-author
4.5 Percentage of patents with a foreign co-investor
5. Output and Impact
5.1 Scientific publications per 100 000 population
5.2 Share of countries in total EPO patent application
5.3 Share of firm creating any innovative output
5.4 GDP per employed person
5.5 Share of knowledge-based industries in total value added
5.6 Share medium-high technology industries in manufacturing export
5.7 Technology balance of payments as a percentage of GDP

European Union knowledge economy indicators

Source: (European Commission, 2010b, 2014)

1. Innovation Drivers (5)
1.1 New S&E graduates per 1000 population aged 20-29
1.2 Population with tertiary education per 100 population aged 25-64
1.3 Number of broadband lines per 100 population
1.4 Participation in life-long learning per 100 population aged 25-64
1.5 Percentage population age 20-24 completed secondary education
2. Knowledge Creation (5)
2.1 Public R&D expenditures (% of GDP)
2.2 Business R&D expenditures (% of GDP)
2.3 Share of medium high-tech and high-tech R&D
2.4 Share of enterprises receiving public funding for innovation
2.5 Share of University R&D expenditures financed by business sector
3. Innovation and Entrepreneurship (6)

3.1 SMEs innovating in-house (% of SME)
3.2 Innovative SMEs co-operating with others (% of SMEs)
3.2 Innovative expenditures (% of turnover)
3.4 Early-stage venture capital (% of GDP)
3.5 ICT expenditure (% of GDP)
3.6 SMEs using non-technological change (% of SMEs)
4. Application (5)
4.1 Employment in high-tech services (% of total workforce)
4.2 Exports of high technology products as share of total exports
4.3 Sales of new-to-market products (% of turnover)
4.4 Sales of new-to-firm not new-to-market products (% of turnover)
4.5 Employment in medium-high tech manufacturing (% of total)
5. Intellectual Property (5)
5.1 New European Patent Office patents per million
5.2 New United States Patent and Trademark Office per million
5.3 New Triad patents per million population
5.4 New community trademarks per million population
5.5 New community industrial designs per million population

APEC knowledge economy indicators

Source: (APEC Economic Committee, 2000, p. 195)

1. Business Environment
1.1 Knowledge based Industries as % of GDP
1.2 Services Exports as of GDP
1.3 High-Tech Exports as of GDP
1.4 Foreign Direct Investment inward flow as % of GDP
1.5 Government transparency rating by World Competitiveness Yearbook
1.6 Financial transparency rating by World Competitiveness Yearbook
1.7 Competition policy rating by World Competitiveness Yearbook
1.8 Openness rating by World Competitiveness Yearbook
2. ICT Infrastructure
2.1 Number of mobile telephones in use per 1000 inhabitants
2.2 Number of telephone mainlines in use per 1000 inhabitants
2.3 Number of computers per 1000 inhabitants
2.4 Number of internet users as % of population
2.5 Internet hosts per 10000
2.6 Expected e-commerce Revenues, M$US
3. Innovation System
3.1 Scientists Engineers in R&D per million of the population
3.2 Full-time researchers per million of the population
3.3 Gross Expenditure on R&D (% of GDP)

3.4 Business Expenditure on R&D (% of GDP)
3.5 US Patents per annum
3.6 The number of technological cooperation among companies
3.7 The number of technological cooperation between company-university
4. Human Resource Development
4.1 Secondary enrolment (% of age group)
4.2 Natural Sciences Graduates per annum
4.3 Knowledge Workers (% of labor force)
4.4 Newspaper (per 1000 inhabitants)
4.5 Human Development Index

Appendix 10 Code of the PHP programme for computing entropies, mutual information and transmission power

1. Content of the form file

```
<?php
echo "<table align=center>";
echo "<form action='tridim-calcul.php' method=post>";
	echo "<tr>";
		echo "<td>Label</td>";
		echo "<td><input type='text' name='id' size=15></td>";
	echo "</tr>";
	echo "<tr>";
		echo "<td> U value </td>";
		echo "<td><input type='text' name='u' size=15></td>";
	echo "</tr>";
	echo "<tr>";
		echo "<td> I value </td>";
		echo "<td><input type='text' name='i' size=15></td>";
	echo "</tr>";
	echo "<tr>";
		echo "<td> G value </td>";
		echo "<td><input type='text' name='g' size=15></td>";
	echo "</tr>";
	echo "<tr>";
		echo "<td> UI value </td>";
		echo "<td><input type='text' name='ui' size=15></td>";
	echo "</tr>";
	echo "<tr>";
		echo "<td> UG value </td>";
		echo "<td><input type='text' name='ug' size=15></td>";
	echo "</tr>";
	echo "<tr>";
		echo "<td> IG value </td>";
		echo "<td><input type='text' name='ig' size=15></td>";
	echo "</tr>";
	echo "<tr>";
		echo "<td> UIG value </td>";
		echo "<td><input type='text' name='uig' size=15></td>";
	echo "</tr>";
	echo "<tr>";
		echo "<td> O value </td>";
		echo "<td><input type='text' name='o' size=15></td>";
```

```
            echo "</tr>";
            echo "<tr>";
                        echo "<td> <input type=reset value=Reset> </td>";
                        echo "<td> <input type=submit value=Calculate> </td>";
            echo "</tr>";
echo "</table>";
?>
```

2. Content of the tridim-calcul.php file

```
<?php

# Defining the entropy function
function p_entropy($p)
{
            if ($p>0) { $p_entropy=-$p*log($p,2); }
else {$p_entropy=-0;
}
return $p_entropy;
}

# Reading input data
$id=$_POST['id'];
$u=$_POST['u'];
$i=$_POST['i'];
$g=$_POST['g'];
$ui=$_POST['ui'];
$ug=$_POST['ug'];
$ig=$_POST['ig'];
$uig=$_POST['uig'];
$o=$_POST['o'];
if ($o=="") {$o=0;}

# Calculation of the total output
$total = $u+$i+$g+$ui+$ug+$ig+$uig+$o;
#if ($total==0) {$total=1;}

 #Calculation of the probabilities
 $p_u = $u/$total;
 $p_i = $i/$total;
 $p_g = $g/$total;
 $p_ui = $ui/$total;
 $p_ug = $ug/$total;
 $p_ig = $ig/$total;
```

```
 $p_uig = $uig/$total;
 $p_o = $o/$total;
if ($o==0) {$M=7;} else {$M=8;}

 #calculation of sectorial entropies
 $u0 = $u+$ui+$ug+$uig;
 $i0 = $i+$ui+$ig+$uig;
 $g0 = $g+$ug+$ig+$uig;
 $p_u0 = $u0/$total;
 $p_i0 = $i0/$total;
 $p_g0 = $g0/$total;

$hu = p_entropy($p_u0) + p_entropy(1-$p_u0);
$hi = p_entropy($p_i0) + p_entropy(1-$p_i0);
$hg = p_entropy($p_g0) + p_entropy(1-$p_g0);

 # Computation of bilateral entropies
$hui = p_entropy($p_o + $p_g) + p_entropy($p_i + $p_ig) + p_entropy($p_u + $p_ug)
+ p_entropy($p_ui + $p_uig) ;
$hug = p_entropy($p_o + $p_i) + p_entropy($p_g + $p_ig) + p_entropy($p_u + $p_ui)
+ p_entropy($p_ug + $p_uig) ;
$hig = p_entropy($p_o + $p_u) + p_entropy($p_g + $p_ug) + p_entropy($p_i + $p_ui)
+ p_entropy($p_ig + $p_uig);

 # Computation of tri lateral entropy
 $huig = p_entropy($p_u) + p_entropy($p_i) + p_entropy($p_g) + p_entropy($p_ui) +
p_entropy($p_ug) + p_entropy($p_ig) +  p_entropy($p_uig) + p_entropy($p_o);

  # Computation of the mutual informations
  $tui = $hu + $hi - $hui;
  $tug = $hu + $hg - $hug;
  $tig = $hi + $hg - $hig;
  $tuig = $hu + $hi +$hg - $hui - $hig - $hug + $huig;

  #Computation of the transmission power
  $tuig_min = $huig - $hu - $hi - $hg;
  if ($tuig<0) {$tp=$tuig/$tuig_min;} else if ($tuig>0) {$tp=$tuig/$huig;} else $tp=0;

#Display of the results on screen
echo "<b><font size=4><p align=center>Execution results</font></b>";
echo "<table align=center border>";
	echo "<tr>";
		echo "<td>ID</td>";
		echo "<td>U</td>";
		echo "<td>I</td>";
```

```
        echo "<td>G</td>";
        echo "<td>UI</td>";
        echo "<td>UG</td>";
        echo "<td>IG</td>";
        echo "<td>UIG</td>";
        echo "<td>O</td>";
        echo "<td>Total</td>";
        echo "<td>Hu</td>";
        echo "<td>Hi</td>";
        echo "<td>Hg</td>";
        echo "<td>Hui</td>";
        echo "<td>Hug</td>";
        echo "<td>Hig</td>";
        echo "<td>Huig</td>";
        echo "<td>tui</td>";
        echo "<td>tug</td>";
        echo "<td>tig</td>";
        echo "<td>tuig</td>";
        echo "<td>tp</td>";
        echo "<td>t(u:i:g)</td>";
        echo "<td>h(u:i:g)</td>";
        echo "<td>Eff</td>";
echo "</tr>";
echo "<tr>";
        echo "<td>", $id,"</td>";
        echo "<td>", $u,"</td>";
        echo "<td>", $i, "</td>";
        echo "<td>", $g,"</td>";
        echo "<td>", $ui,"</td>";
        echo "<td>", $ug,"</td>";
        echo "<td>", $ig,"</td>";
        echo "<td>", $uig,"</td>";
        echo "<td>", $o,"</td>";
        echo "<td>", $total,"</td>";
        echo "<td>", round($hu*1000,3),"</td>";
        echo "<td>", round($hi*1000,3), "</td>";
        echo "<td>", round($hg*1000,3),"</td>";
        echo "<td>", round($hui*1000,3),"</td>";
        echo "<td>", round($hug*1000,3),"</td>";
        echo "<td>", round($hig*1000,3),"</td>";
        echo "<td>", round($huig*1000,3),"</td>";
        echo "<td>", round($tui*1000,3),"</td>";
        echo "<td>", round($tug*1000,3),"</td>";
        echo "<td>", round($tig*1000,3),"</td>";
        echo "<td>", round($tuig*1000,3),"</td>";
```

```
			echo "<td>", round($tp*100,2),"</td>";
			echo "<td>", round(-$tuig_min*1000,3),"</td>";
			echo "<td>", round(($hu+$hi+$hg)*1000,3),"</td>";
			echo "<td>", round($huig*100/log($M,2),2),"</td>";
		echo "</tr>";
		echo "</table>";

#Sending result into a file
$file1='entropy.txt';
if (!file_exists($file1))
		{
		file_put_contents($file1,"ID;U;I;G;UI;UG;IG;UIG;O;Total;Hu;Hi;Hg;Hui;Hug;Hig
;Huig;tui;tug;tig;tuig;tp;t(u:i:g);h(u:i:g);Eff\n");
		}
file_put_contents($file1, $id.";", FILE_APPEND);
file_put_contents($file1, $u.";", FILE_APPEND);
file_put_contents($file1, $i.";", FILE_APPEND);
file_put_contents($file1, $g.";", FILE_APPEND);
file_put_contents($file1, $ui.";", FILE_APPEND);
file_put_contents($file1, $ug.";", FILE_APPEND);
file_put_contents($file1, $ig.";", FILE_APPEND);
file_put_contents($file1, $uig.";", FILE_APPEND);
file_put_contents($file1, $o.";", FILE_APPEND);
file_put_contents($file1, $total.";", FILE_APPEND);
file_put_contents($file1, round($hu*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($hi*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($hg*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($hui*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($hug*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($hig*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($huig*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($tui*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($tug*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($tig*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($tuig*1000,3).";", FILE_APPEND);
file_put_contents($file1, round($tp*100,2).";", FILE_APPEND);
file_put_contents($file1, round(-$tuig_min*1000,3).";", FILE_APPEND);
file_put_contents($file1, round(($hu+$hi+$hg)*1000,3).";", FILE_APPEND);
file_put_contents($file1, round(($huig/log($M,2))*100,2).";", FILE_APPEND);
file_put_contents($file1, "\n", FILE_APPEND);
?>
```

Appendix 11 Search strategy to collect the domestic, foreign and global data for South Korea from the local database

Search expressions #1 to #7 collect the domestic level data, search expressions #8 to #14 collect foreign level data and search expression #15 to #21 collect global level data. Searches #22 and #23 give respectively the share of international collaboration and the total output of the country.

#1: UNIV-KOREA selects all records with at least one Korean-based university in affiliation;

#2: INDU-KOREA selects all records with at least one Korean-based industry in affiliation;

#3: GOV-KOREA selects all records with at least one Korean-based government in affiliation;

#4: #1 * #2 selects all records with at least one Korean-based university AND one Korean-based industry in affiliation;

#5: #1 * #3 selects all records with at least one Korean-based university AND one Korean-based government in affiliation;

#6: #2 * #3 selects all records with at least one Korean-based industry AND one Korean-based government in affiliation;

#7: #1 * #2 * #3 selects all records with at least one Korean-based university AND one Korean-based industry AND one Korean-based government in affiliation.

#8: UNIV-FOREIGN selects all records with at least one non-Korean-based university in affiliation;

#9: INDU-FOREIGN selects all records with at least one non-Korean-based industry in affiliation;

#10: GOV-FOREIGN selects all records with at least one non-Korean-based government in affiliation;

#11: #8 * #9 selects all records with at least one non-Korean-based university AND one Korean-based industry in affiliation;

#12: #9 * #10 selects all records with at least one non-Korean-based university AND one non-Korean-based government in affiliation;

#13: #9 * #10 selects all records with at least one non-Korean-based industry AND one non-Korean-based government in affiliation;

#14: #8 * #9 * #10 selects all records with at least one non-Korean-based university AND one non-Korean-based industry AND one non-Korean-based government in affiliation.

#15: (UNIV-KOREA + UNIV-FOREIGN) selects all records with at least one university in affiliation;

#16: (INDU-KOREA + INDU-FOREIGN) selects all records with at least one industry in affiliation;

#17: (GOV-KOREA + GOV-FOREIGN) selects all records with at least one government in affiliation;

#18: #15 * #16 selects all records with at least one university AND one industry in affiliation;

#19: #15 * #17 selects all records with at least one university AND one government in affiliation;

#20: #16 * #17 selects all records with at least one industry AND one government in affiliation;

#21: #15 * #16 * #17 selects all records with at least one university AND one industry AND one government in affiliation.

#22: UNIV-FOREIGN + INDU- FOREIGN + GOV- FOREIGN + NC- FOREIGN selects all the records with at least a foreign affiliation.

#23: UNIV-KOREA + INDU-KOREA + GOV-KOREA + NC-KOREA selects all the records within the database (all records produced by Korea);

Appendix 12 Search strategy to collect the domestic, foreign and global data for West African countries from the local database

Search expressions #1 to #7 collect the domestic level data, search expressions #15 to #23 select foreign level data, and search expression #24 to #30 collect global level data; others search expression constitutes intermediate steps of the strategy.

#1: UNIV-COUNTRY selects all records with at least one COUNTRY-based university in affiliation;

#2: INDU- COUNTRY selects all records with at least one COUNTRY-based industry in affiliation;

#3: GOV- COUNTRY selects all records with at least one COUNTRY-based government in affiliation;

#4: #1 * #2 selects all records with at least one COUNTRY-based university AND one COUNTRY-based industry in affiliation;

#5: #1 * #3 selects all records with at least one COUNTR-based university AND one COUNTRY-based government in affiliation;

#6: #2 * #3 selects all records with at least one COUNTRY-based industry AND one COUNTRY-based government in affiliation;

#7: #1 * #2 * #3 selects all records with at least one COUNTRY-based university AND one COUNTRY-based industry AND one COUNTRY-based government in affiliation.

#8: UNIV-COUNTRY + INDU- COUNTRY + GOV- COUNTRY + NC- COUNTRY selects all the records produced by COUNTRY;

#9: UNIV-FOREIGN + INDU- FOREIGN + GOV- FOREIGN + NC- FOREIGN selects all the records with at least a foreign affiliation (from the West African region erspectoive).

#10: UNIV-REGION selects all records with at least one West African country-based university in affiliation, except the selected country;

#11: INDU-REGION selects all records with at least one West African country-based industry in affiliation, except the selected country;

#12: GOV-REGION selects all records with at least one West African country-based government in affiliation, except the selected country;

#13: NC-REGION selects all records with at least one non classified addressed in any West African country in affiliation, except the selected country;

#14: #10 * #11 * #12 * #13 selects all records with at least one West African address but with no COUNTRY address

#15: #9 + #14: selects all records with at least one foreign address (both from the West African region and COUNTRY perspective);

#16: #8 + #15: selects all records having resulted from international collaboration from COUNTRY perspective;

#17: ((UNIV-FOREIGN + #10) *#8) selects all records with at least one foreign university address (from COUNTRY perspective);

#18: ((INDU-FOREIGN + #11) * #8: selects all records with at least one foreign industry address (from COUNTRY perspective);

#19: ((GOV-FOREIGN + #12) * #8: selects all records with at least one government address (from COUNTRY perspective);

#20: #17 * #18: selects all records with at least one foreign university address AND one foreign industry address (from COUNTRY perspective);

#21: #17 * #19: selects all records with at least one foreign university address AND one foreign government address (from COUNTRY perspective);

#22: #18 * #19: selects all records with at least one foreign industry address AND one foreign government address (from COUNTRY perspective);

#23: #8 * #17 * #18 * #19 *: selects all records with at least one foreign university address AND one foreign industry address AND one foreign government address (from COUNTRY perspective);

#24: #17 + #1: selects all records with at least one university address (both foreign and domestic from COUNTRY perspective);

#25: #18 + #2: selects all records with at least one industry address (both foreign and domestic from COUNTRY perspective);

#26: #19 + #3: selects all records with at least one government address (both foreign and domestic from COUNTRY perspective);

#27: #24 * #25: selects all records with at least one university address AND one industry address (both foreign and domestic from COUNTRY perspective);

#28: #24 * #26: selects all records with at least one university address AND one government address (both foreign and domestic from COUNTRY perspective);

#29: #25 * #26: selects all records with at least one industry address AND one government address (both foreign and domestic from COUNTRY perspective);

#30: #24 * #25 * #26: selects all records with at least one university address AND one industry address AND one government address (both foreign and domestic from COUNTRY perspective);

Appendix 13 Equivalence between Equations (13-2) and (13-3)

Equation (13-3) is $T_{XYZ} = (H_X - H_{XZ}) + (H_Y - H_{XY}) + (H_Z - H_{YZ}) + H_{XYZ}$.

It leads to

$$T_{XYZ} = (-H_{XZ} + H_X) + (-H_{XY} + H_Y) + (-H_{YZ} + H_Z) + H_{XYZ} \tag{13-37}$$

and

$$T_{XYZ} = -H_{Z|X} - H_{X|Y} - H_{Y|Z} + H_{XYZ} \tag{13-38}$$

According to Equation (13-5), $H_{XY} - H_X = H_{Y|X}$. Similarly,

$$H_{XY} - H_Y = H_{X|Y} \tag{13-39}$$

The expression of $H_{X|Y}$ drawn from Equation (13-5) gives

$$H_{XY} = H_{Y|X} + H_X \tag{13-40}$$

Replacing Equation (13-40) into (13-39) leads to

$$H_{X|Y} = H_{Y|X} + H_X - H_Y \tag{13-41}$$

We could write, similarly:

$$H_{Z|X} = H_{X|Z} + H_Z - H_X \tag{13-42}$$

and

$$H_{Y|Z} = H_{Z|Y} + H_Y - H_Z \tag{13-43}$$

Thus, Equation 13-38 becomes:

$$T_{XYZ} = -(H_{X|Z} + H_Z - H_X) - (H_{Y|X} + H_X - H_Y) - (H_{Z|Y} + H_Y - H_Z) + H_{XYZ} \tag{13-44}$$

and

$$T_{XYZ} = -H_{X|Z} - H_Z + H_X - H_{Y|X} - H_X + H_Y - H_{Z|Y} - H_Y + H_Z + H_{XYZ} \tag{13-45}$$

$$T_{XYZ} = -H_{X|Z} + (H_Z + H_Z) + (H_X - H_X) - H_{Y|X} + (H_Y - H_Y) - H_{Z|Y} + H_{XYZ} \tag{13-46}$$

and finally

$$T_{XYZ} = -H_{X|Z} - H_{Y|X} - H_{Z|Y} + H_{XYZ} \tag{13-47}$$

which is equivalent to the expression of T_{XYZ} in Equation (13-2).