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Synergy within the West African Triple Helix innovation systems as measured with game theory

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Abstract

Purpose – University, industry and government relationships, known under the Triple Helix, have been studied under various aspects. The West African region and countries have been analysed with mutual information and transmission power, two information theory-based indicators. The purpose of this paper is to portray the landscape of West African Triple Helix innovation systems using three main game theory indicators (core, Shapley value and nucleolus) with the objective to measure the synergy within the selected innovation systems.
Design/methodology/approach – The collaboration between university, industry and government is modelled as a three-person coalitional game. Bibliographical data of selected countries were collected from Web of Science and organised according to collaboration patterns between the three actors. The characteristic functions of the games were computed, the cores plotted, the Shapley values and the nucleoli computed.
Findings – Either university or government has more power to create and lead to synergy; government shows solidarity towards university and industry in most of countries; and they are joined in their efforts by industry in two countries. The core exists in all the countries meaning that all the selected innovation systems present synergy; however, the extent is limited and varies over countries.
Research limitations/implications – Innovation includes all research products; however, this study focuses on publications only.
Originality/value – Synergy within a Triple Helix innovation system is studied up to now with information theory indicators. The paper portrays the landscape of West African Triple Helix innovation systems using three main game theory indicators: the core, the Shapley value and the nucleolus and gives a new way to study university, industry and government relationships.

Keywords Africa, Innovation

Paper type Research paper

Introduction

Africa's share to the world science is negligible, less than 1 per cent (cf. Adams *et al.*, 2010). Indeed, science in Africa is still at its early stage (UNESCO, 2010, 2015); the entire continent annual scientific output is lower to that of the Netherlands (UNESCO Institute of Statistics, 2005). The review of the West African research landscape reveals that African countries scientific publishing is extraverted: more than one half of the West African science are co-authored with a foreign country (Mêgnigbêto, 2013a); research on the continent is lead in the shade or the wake of development projects and programmes financed by donors (Bierschenk and Mongbo, 1995) meaning that most of the research carried out in these countries is contributed to or initiated by foreign countries; and, as a result, science in Africa is dominated by foreign countries, mainly former colonial power. Innovation in this part of the world, therefore, is dominated by foreign countries.

In the Schumpeterian economic theory, development is described as a historical process of structural changes, substantially driven by innovation (Schumpeter, 1934, 1976, 2004);

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therefore, a low level of scientific production means a low level of novelty production, a low level of knowledge production and results in a low level of innovation. Paradoxically, West Africa is among the poorest regions of the Word, in terms of wealth production; it is also facing the biggest challenges: poverty, hunger, armed conflicts, bad governance, population growth, access to education and health cares, etc. The region needs to produce more knowledge to take up these challenges. So, there is a need to understand the extent to which knowledge produced by West Africa-based researchers helps the region in wealth creation.

West Africa is one of the five African regions as determined by the African Union. It counts 15 countries; in the alphabetic order, these are: Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, 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, UK and Portugal. All the West African countries are together members of the Economic Community of West African States (ECOWAS), a regional economic integration organisation. Both African governments and integration institutions at regional and continental levels recognise the role of science, technology and innovation (STI) in development. In early 2012, the region adopted the ECOPOST, i.e. the ECOWAS Policy on Science and Technology (Commission de la CEDEAO, 2012), which should help Member States scientists to compete and to exchange with the best research teams worldwide. Also, at a national level, policies have been set up to make research contribute to improve life conditions. ECOWAS and African Union Member States have committed in many occasions to allot 1 per cent of their gross domestic product to fund research activities, in accordance with the Lagos Action Plan (Organisation of African Unity, 1980).

The Triple Helix of university–industry–government relationships is a conceptual framework introduced by Etzkowitz and Leydesdorff (1995, 2000) as one of the variants of the non-linear model of innovation (Etzkowitz *et al.*, 2000; Leydesdorff, 2012; Meyer *et al.*, 2014). It has the functions of novelty production, wealth generation and normative control (Leydesdorff, 2016; Leydesdorff and Park, 2014). According to the theory, innovation is the outcome of the synergy resulting from the interactions between the three main actors of the system: university, industry and government (Leydesdorff and Etzkowitz, 2001). Shannon's (1948) information theory indicators, namely, the mutual information (Leydesdorff, 2003) and the transmission power (Mêgnigbêto, 2014a), were used to measure the synergy within a Triple Helix innovation system.

This study seeks to measure the synergy within the West African innovation systems using the game theory; specifically, it aims to determine the profile of the 15 West African countries regarding the core, the Shapley value and the nucleolus. We formulate the following research questions:

RQ1. What are the rules of the Triple Helix game of selected countries?

RQ2. How do selected countries perform with regard to game theory indicators?

RQ3. How does selected countries profile compare with mutual information or transmission power?

The paper intends to answer these research questions. It is structured as follows: in the second (next) section, we conduct a literature review on innovation studies on Africa or West Africa with a particular emphasis on the Triple Helix model; we explain the rules of the Triple Helix game; the third section describes the method of data collection and treatment; the fourth section presents the analyses; the fifth section discusses the results; and the last section summarises the main findings and concludes.

Literature review

Much has been written on STI in Africa, from various disciplines perspective. However, studies dealing with the relations between university, industry and government are

even scare. Some studies have dealt with university–industry–government relationships in African countries specifically (e.g. Etzkowitz and Dzisah, 2007 for the whole Africa; Nwagwu, 2008 for Nigeria; Patra and Muchie, 2018; Taylor, 2004 for South Africa). In 2012, the Association of African Universities conducted a survey in university–industry linkages in Africa (Ssebuwufu *et al*., 2012); Zavale and Langa (2018) reviewed papers dealing with university–industry linkages in Sub-Saharan Africa. The aforementioned studies did not use any indicator; they neither studied the whole West Africa region nor used any bibliographic database. A range of studies where devoted to the Triple Helix relationships in West Africa, both at regional and national levels. They use bibliographic data of the West Africa retrieved from Web of Science and use mutual information and transmission power as indicators of the Triple Helix relationships (Mêgnigbêto, 2013b, 2014b, c, 2015, 2016). Recently, game theory indicators, namely, the core, the Shapley value and the nucleolus, were used to measure the synergy within West African innovation system at the regional level (Mêgnigbêto, 2018a).

Triple Helix and game theory

Informetrics studies having used game theory techniques and tools are scarce: Tol (2012) and Karpov (2014) resorted to Shapley values: the former for assessing research production and impact of schools and scholars, and the latter for allocating publication credit to co-authors; Hayes (2001, 2003) modelled decision making in library cooperation with the cooperative games theory; and Schubert and Glänzel (2008) showed that ternary diagram could serve to study research collaboration and citations. Some papers introduced the game theory in the study of either innovation system in general (Baniak and Dubina, 2012 gave a review of them) or the Triple Helix in particular. Carayannis and Dubina (2014) and Dubina and Carayannis (2015) demonstrated that game theory could help in understanding the behaviour of innovation actors; Dubina (2015a, b) modelled the Triple Helix relationships with the game theory; however, the scope of his reflexion was limited to project funding. Not only did not he deal with publications, but he did not either propose any indicator to measure the synergy within the Triple Helix framework also. As he wrote, it was a "first attempt to formalize the concept of the Triple Helix of university-government-industry interactions in innovation activities with game theory" (Dubina, 2015a, p. 33, b, p. 40).

Recently, game theory indicators were used to study some countries or regions innovation system, mainly South Korean and the West African region (Mêgnigbêto, 2018a) on the one hand, four developing countries (USA, UK, Germany and France) and four emerging ones (Russia, India, Brazil and China) on the other hand (Mêgnigbêto, 2018b). The main findings of the two papers are: the biggest Triple Helix sphere science producer has more power to convince partners to join him for the creation of the synergy; government and its partners show solidarity to maintain the synergy; the bilateral partnership between university and government has more interest in the game; contribution of actors to the core of the game ranks university or government first then industry in third position; the contribution of industry is always limited due to the share of that actor to the total output; note that the unit of analysis (publication count) may have affected this result; and the position of the core on the ternary diagram reflects the state intervention in the economy.

Methods and data

In a Triple Helix innovation system, actors interact mainly by means of collaboration. By doing so, they pursue the goal of maximising the number of papers they publish individually and collectively; they form coalitions which make the Triple Helix of university–industry–government relationships a cooperative game. A cooperative game is characterised by a set of players, coalitions they may form and payoffs or utility. The relations between coalitions and payoffs or utility are called characteristic function.

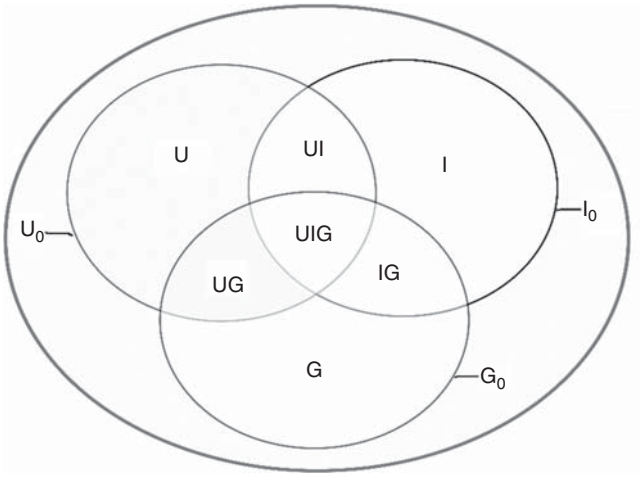
Rules of the Triple Helix game

According to Mêgnigbêto (2017, 2018a), the Triple Helix relationship is a three-person cooperative game with transferable utility. The players are the three Triple Helix actors: university (u), industry (i) and government (g). The set of coalitions they may form is $P = \{\varnothing, \{u\}, \{i\}, \{g\}, \{u,i\}, \{u,g\}, \{i,g\}, \{u,i,g\}\}$. Let υ be the characteristic function of the game; it awards to each coalition of players its payoff, e.g. the number of papers it published or the corresponding percentage share. Let us consider Figure 1 which represents the basic configuration of the Triple Helix in term of number of publications per sphere. For the simplification purpose, we will write, for example, ui instead of $\{u, i\}$ to designate the coalition formed by players u and i.

The characteristic function of the Triple Helix game is as follows (Mêgnigbêto, 2017, 2018a):

$$\begin{cases} \upsilon(\emptyset) = 0 \\ \upsilon(u) = \mathrm{U} \\ \upsilon(i) = \mathrm{I} \\ \upsilon(g) = \mathrm{G} \\ \upsilon(ui) = \mathrm{U}+\mathrm{I}+\mathrm{UI} \\ \upsilon(ug) = \mathrm{U}+\mathrm{G}+\mathrm{UG} \\ \upsilon(ig) = \mathrm{I}+\mathrm{G}+\mathrm{IG} \\ \upsilon(uig) = \mathrm{U}+\mathrm{I}+\mathrm{G}+\mathrm{UI}+\mathrm{UG}+\mathrm{IG}+\mathrm{UIG} \end{cases}, \tag{1}$$

where U, I, G represent the number of papers university, industry and government published on their own respectively; UI, UG, IG represent the number of papers university and industry, university and government, industry and government co-authored, respectively; and UIG the number of papers the three actors co-authored. UI, UG and IG exclude UIG (Mêgnigbêto, 2017, 2018a). To obtain the characteristic function in percentage,



Source: Mêgnigbêto (2017, 2018a)

Figure 1.
Triple Helix spheres' contributions to the Triple Helix relationships

one should multiply by 100 the right term of each equation and divide the result by the total number of papers within the system given by $\upsilon(uig) = \mathrm{U}+\mathrm{I}+\mathrm{G}+\mathrm{UI}+\mathrm{UG}+\mathrm{IG}+\mathrm{UIG}$ (see Mêgnigbêto, 2018a).

Core, Shapley value and nucleolus as indicators

The core of the Triple Helix game is determined by the number of publications each actor produced on its own (the lower bound) and the total number of publications that actor produced within the system, included in collaboration with other actors (the upper bound), under the condition that the three values add up to the total number of publications in the considered set. In its analytic form, the core of a Triple Helix cooperative game is the set of values x_u, x_i and x_g of the utility of players u, i and g, respectively, so that (Mêgnigbêto, 2018a):

$$\begin{cases} \upsilon(u) \leqslant x_u \leqslant \upsilon(uig) - \upsilon(ig) \\ \upsilon(i) \leqslant x_i \leqslant \upsilon(uig) - \upsilon(ug) \\ \upsilon(g) \leqslant x_g \leqslant \upsilon(uig) - \upsilon(ui) \\ x_u + x_i + x_g = \upsilon(uig) \end{cases}. \tag{2}$$

The core may be represented in a graphical form also. The core expresses actors' interests and constraints on these interests; it indicates the margin innovation actors have to bind agreements with the twofold target of creating synergy and redistributing benefits. The core determines existence and level of synergy within a Triple Helix innovation system (Mêgnigbêto, 2018a).

The Shapley value is the value an actor expects before the game begins or realizes after the game ends (Roth, 1988a, b). Within the framework of the Triple Helix relationships, Mêgnigbêto (2018a) interpreted the Shapley value as the power of an actor to lead to and create synergy; it is the power an actor has to convince partners to collaborate with him or to form a coalition. Shapley (1952, 1953) gave a formula to compute this value. The Shapley value is the triplet S_u, S_i, S_g for players' university, industry and government, respectively, so that (Mêgnigbêto, 2018a):

$$\begin{cases} S_u = \frac{2\upsilon(uig) + 2\upsilon(u) + \upsilon(ui) + \upsilon(ug) - 2\upsilon(ig) - \upsilon(i) - \upsilon(g)}{6} \\ S_i = \frac{2\upsilon(uig) + 2\upsilon(i) + \upsilon(ui) + \upsilon(ig) - 2\upsilon(ug) - \upsilon(u) - \upsilon(g)}{6} \\ S_g = \frac{2\upsilon(uig) + 2\upsilon(g) + \upsilon(ig) + \upsilon(ug) - 2\upsilon(ui) - \upsilon(i) - \upsilon(u)}{6} \end{cases}. \tag{3}$$

The nucleolus measures excesses in the distributions of the total payoff in order to indicate the "more acceptable" one by players (Kohlberg, 1971; Schmeidler, 1969). According to Mêgnigbêto (2018a), in the framework of the Triple Helix relationships, the nucleolus is the efforts of solidarity made by an actor (and its partners) to maintain synergy within the innovation system. The nucleolus has no analytic formula. It is hard to be computed (Sziklai, 2015), indeed, it requires a step-by-step approach so that it is better to use an algorithm or software application for its computation. Sziklai (2015) established several methods on the computation of the nucleolus as well as the corresponding theory. Nowadays, there are many software applications that allow computing the nucleolus; even though using same data, they always do not yield the same results. Guajardo and Jorusten (2015) revealed common mistakes in computing the nucleolus; Cano-Berlanga *et al.* (2017) claimed that the package "Game theory" for the R statistical software (R Development Core Team, 2017) takes into account these criticisms and produces robust results.

Research data collection and treatment

West African region has been analysed recently, both at the regional and national level by Mêgnigbêto (2015, 2016) with the mutual information and the transmission power as indicators of the synergy within the Triple helix innovation system; data used were collected from the Web of Science[1] over a ten-year period (2001–2010). Mêgnigbêto (2015, 2016) presented data according to the Triple Helix spheres, e.g. innovation actors and their bi- or tri-lateral collaborations. We introduced these data into a spreadsheet for the computation of the characteristic functions according to the System 1. Then, the upper and lower bounds to each actor's interests were determined to form the core. The "ggtern" package (Hamilton, 2016) for the R statistical software (R Development Core Team, 2017) was used to plot the lines determining the lower and upper bounds of the core on the ternary diagram. The diagram was produced in a Scalable Vector Graphics format file (World Wide Web Consortium, 2011) and the Inkscape software application (Bah, 2009; Inkscape Team, 2017) was used to colour the surface area of the core. The Shapley value and the nucleolus were computed using the "Game Theory" package (Cano-Berlanga *et al.*, 2017) for the R statistical software (R Development Core Team, 2017).

Results

Countries' total output and Triple Helix spheres' shares

Science in West Africa is dominated by Nigeria, the local giant, that produces on its own more than half of the regional total output (Mêgnigbêto, 2013a). Therefore, the remaining 14 countries produce less than Nigeria. Note that the production of Cape Verde, Liberia and Sierra Leone are negligible (less than or around one paper per month over a decade). Countries' production by Triple Helix spheres are plotted in Figures 2 and 3. It reveals that university is the biggest science producer in 11 countries (Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Mali, Nigeria, Senegal, Sierra Leone and Togo) and government in the four remaining countries (Guinea, Guinea Bissau, Liberia and Niger). The industrial output is very limited over the region. In eight countries (Benin, Cape Verde, Cote d'Ivoire, Ghana, Guinea, Liberia, Mali, Niger and Togo) industry has no output on its own, except in collaboration only. In Guinea Bissau and Liberia, industry has produced no paper, neither on its own nor in collaboration. As a result, the bilateral collaborations industry involved in are weaker or null in some countries. The trilateral collaboration occurs everywhere except in three countries (Guinea Bissau, Liberia and Niger).

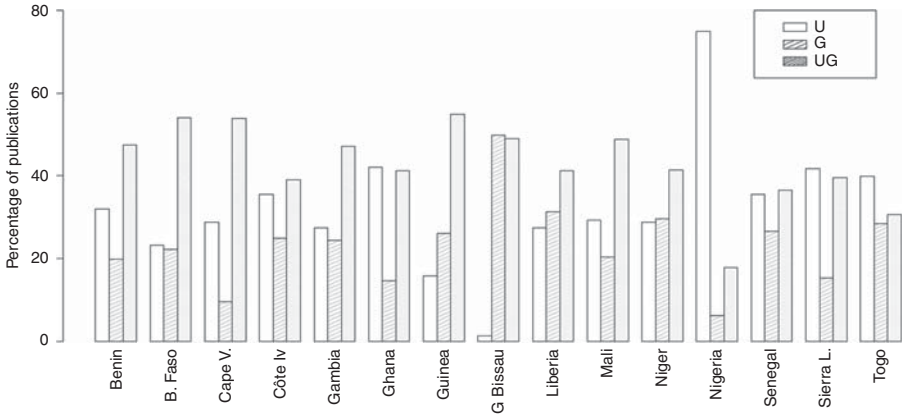


Figure 2.
Outputs of the Triple Helix spheres (U, G and UG) in selected innovation systems

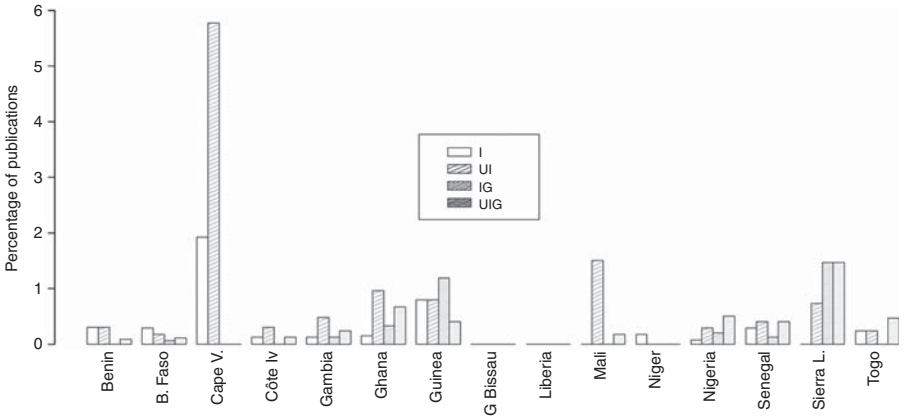


Figure 3.
Outputs of the Triple Helix spheres (I, UI, IG and UIG) in selected innovation systems

Notes: Industry's percentage shares and contributions are very limited compared with those of other players; therefore, we plotted them separately to allow relevant analyses

Characteristic functions

Table I gives the characteristic function of the game for each of the selected innovation system. In countries where university is the biggest science producer, coalitions it is involved in earning the largest utility, so, the ranking of coalitions by decreasing payoff is *ug*, *ui*, *u*, *ig*, *g*, *i*; and, in countries where government is the biggest science producer, coalitions it is involved in are ranked first, so the order is *ug*, *ig*, *g*, *ui*, *u*, *i*. In Guinea Bissau and Liberia, the two countries where industry has no output at all (neither on its own nor with collaboration), coalitions *u* and *ui*, *g* and *ig*, and *ug* and *uig* have pairwise the same utility.

Cores

Analytic form. The analytical form of the core of the selected innovation systems is shown in Table II. It presents the bounds of innovation actors' interests in the knowledge creation game. The lower bound represents the share of an actor when he operates alone and the upper one the share he achieves when he accepts to collaborate for the target of synergy producing.

Table I.
Characteristic functions of the West African Triple Helix games

	u	*i*	*g*	*ui*	*ug*	*ig*	*uig*
Benin	32.04	0	19.89	32.12	99.32	20.20	100
Burkina Faso	23.19	0.06	22.17	23.36	99.38	22.51	100
Cape Verde	28.85	0	9.62	28.85	92.31	11.54	100
Cote d'Ivoire	35.59	0	24.94	35.71	99.46	25.06	100
Gambia	27.52	0.12	24.48	27.88	99.03	24.73	100
Ghana	42.05	0.32	14.68	43.04	97.91	15.15	100
Guinea	15.81	1.19	26.09	17.39	96.84	28.06	100
Guinea Bissau	1.32	0	49.78	1.32	100	49.78	100
Liberia	27.45	0	31.37	27.45	100	31.37	100
Mali	29.31	0	20.32	29.48	98.33	20.32	100
Niger	28.86	0	29.70	28.86	99.83	29.87	100
Nigeria	74.91	0.20	6.23	75.61	98.95	6.49	100
Senegal	35.55	0.12	26.65	36.07	98.80	27.05	100
Sierra Leone	41.61	1.46	15.33	44.53	96.35	16.79	100
Togo	39.86	0	28.57	40.32	99.08	28.80	100

Country	Benin	Burkina Faso	Cape Verde
Core	$\begin{cases} 32.04 \leqslant x_u \leqslant 79.80 \\ 0 \leqslant x_i \leqslant 0.68 \\ 19.89 \leqslant x_g \leqslant 67.88 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 23.19 \leqslant x_u \leqslant 77.49 \\ 0.06 \leqslant x_i \leqslant 0.62 \\ 22.17 \leqslant x_g \leqslant 76.64 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 28.85 \leqslant x_u \leqslant 88.46 \\ 0 \leqslant x_i \leqslant 7.69 \\ 9.62 \leqslant x_g \leqslant 71.15 \\ x_u + x_i + x_g = 100 \end{cases}$
Country	Cote d'Ivoire	Gambia	Ghana
Core	$\begin{cases} 35.59 \leqslant x_u \leqslant 74.94 \\ 0 \leqslant x_i \leqslant 0.54 \\ 24.94 \leqslant x_g \leqslant 64.29 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 27.52 \leqslant x_u \leqslant 75.27 \\ 0.12 \leqslant x_i \leqslant 0.97 \\ 24.48 \leqslant x_g \leqslant 72.12 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 42.05 \leqslant x_u \leqslant 84.85 \\ 0.32 \leqslant x_i \leqslant 2.09 \\ 14.68 \leqslant x_g \leqslant 56.96 \\ x_u + x_i + x_g = 100 \end{cases}$
Country	Guinea	Guinea Bissau	Liberia
Core	$\begin{cases} 15.81 \leqslant x_u \leqslant 71.94 \\ 1.19 \leqslant x_i \leqslant 3.16 \\ 26.09 \leqslant x_g \leqslant 82.61 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 1.32 \leqslant x_u \leqslant 50.22 \\ x_i = 0 \\ 49.78 \leqslant x_g \leqslant 98.68 \\ x_u + x_g = 100 \end{cases}$	$\begin{cases} 27.45 \leqslant x_u \leqslant 68.63 \\ x_i = 0 \\ 31.37 \leqslant x_g \leqslant 72.55 \\ x_u + x_g = 100 \end{cases}$
Country	Mali	Niger	Nigeria
Core	$\begin{cases} 29.31 \leqslant x_u \leqslant 79.68 \\ 0 \leqslant x_i \leqslant 1.67 \\ 2032 \leqslant x_g \leqslant 70.82 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 28.86 \leqslant x_u \leqslant 70.13 \\ 0 \leqslant x_i \leqslant 0.17 \\ 29.70 \leqslant x_g \leqslant 71.14 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 74.91 \leqslant x_u \leqslant 93.51 \\ 0.20 \leqslant x_i \leqslant 1.05 \\ 6.23 \leqslant x_g \leqslant 24.39 \\ x_u + x_i + x_g = 100 \end{cases}$
Country	Senegal	Sierra Leone	Togo
Core	$\begin{cases} 35.55 \leqslant x_u \leqslant 72.95 \\ 0.12 \leqslant x_i \leqslant 1.20 \\ 26.65 \leqslant x_g \leqslant 63.93 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 41.61 \leqslant x_u \leqslant 83.21 \\ 1.46 \leqslant x_i \leqslant 3.65 \\ 15.33 \leqslant x_g \leqslant 55.47 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 39.86 \leqslant x_u \leqslant 71.20 \\ 0 \leqslant x_i \leqslant 0.92 \\ 28.57 \leqslant x_g \leqslant 59.68 \\ x_u + x_i + x_g = 100 \end{cases}$

Table II.
Cores of the West African Triple Helix games

In the case of Guinea Bissau and Liberia, because industry produced neither on its own nor in collaboration, the upper and the lower bounds of this actor's interests are equal to 0. Therefore, instead of an inequality, a simple equality appears in the core's analytical form.

Representation of the core

The dimensions of the core are determined by innovation actors' contribution to its formation which is the difference between upper and lower bounds of actors' interests as expressed in the analytic form. Table III shows that this quantity is almost the same for government and university in all countries; the industrial contribution is limited over all countries (less than 2 per cent, excepted Cape Verde where it reaches 7 per cent). Particularly, in Guinea Bissau and Liberia where the total industrial output is null, the game is reduced to a two-player one, so the grand coalition is *ug* with the total payoff of 100; in these two countries, industry is then a dummy player; e.g. a player with no role in the game or no influence on the outcome (Serrano, 2009). The difference between university and government contribution is less than 0.5 in the majority of countries and around 2 per cent in Sierra Leone. According to Mêgnigbêto (2018b), academic and governmental contribution to the formation of the core determine the core length while that of industry determines the

Table III.
Players' contribution to the formation of the core of the West African Triple Helix games

Country	University	Industry	Government
Benin	47.76	0.68	47.99
Burkina Faso	54.31	0.57	54.48
Cape Verde	59.62	7.69	61.54
Cote d'Ivoire	39.35	0.54	39.35
Gambia	47.76	0.85	47.64
Ghana	42.80	1.77	42.28
Guinea	56.13	1.98	56.52
Guinea Bissau	48.90	0.00	48.90
Liberia	41.18	0.00	41.18
Mali	50.37	1.67	50.21
Niger	41.28	0.17	41.44
Nigeria	18.59	0.85	18.16
Senegal	37.39	1.08	37.27
Sierra Leone	41.61	2.19	40.15
Togo	31.34	0.92	31.11

core's width. Therefore, we conclude that contribution to the core does not take into account the actor dominating the output.

The cores of the 15 West African countries may be categorised with two criteria: the position on the ternary diagram and the contribution of industry to its formation. As Mêgnigbêto (2018b) recorded while studying four developed and four emerging countries, the position of the core on the ternary diagram distinguishes three clusters: first, the university-dominated system where the core is positioned close to the university apex: this cluster groups together three innovation systems, namely, Ghana, Nigeria and Togo; second, the balanced system where university and government produced likely the same output; the core is then positioned at the middle of the side of the triangle opposite to the industrial apex: this cluster groups nine countries, namely, Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Guinea, Liberia, Niger and Sierra Leone; and third, the government-dominated system where the core is positioned near the government apex: this cluster include Guinea Bissau, Mali and Senegal.

The second criteria, contribution of industry to the formation of the core, also distinguished three clusters: countries with null industry contribution, countries with very limited industry contribution ($\leqslant$1 per cent), and countries with appreciable contribution ($\geqslant$1 per cent). In countries with null output, the actors are reduced to two: university and government; the core is, therefore, a segment of the side opposite to the apex Industry. This cluster groups together Liberia and Guinea Bissau. In countries with very limited industrial output, the core is thinner and appears as a line; it is not visible on the ternary diagram; this cluster includes eight countries: Benin, Burkina Faso, Cote d'Ivoire, Gambia, Guinea, Niger, Nigeria and Togo. In the last cluster, the industrial share is appreciable; the core is then more visible. Countries like Cape Verde, Ghana, Guinea, Senegal and Sierra Leone are member of this cluster.

With such criteria of classification, some countries may belong to more than one cluster. We do not present all the 15 cores in this paper, we rather select some of them that illustrate the six following clusters: university-dominated system: Nigeria (Figure 4); the balanced system: Burkina Faso (Figure 5); government dominated system: Senegal (Figure 6); null industry contribution to the formation of the core: Liberia (Figure 7); limited industry contribution to the formation of the core: Burkina Faso (Figure 5); and appreciable industry contribution to the formation of the core: Cape Verde (Figure 8). One may also cross the clusters above to distinguish sub-clusters; for example, the Liberian system belongs both to the null industry contribution to the formation of the core cluster and the balanced cluster.

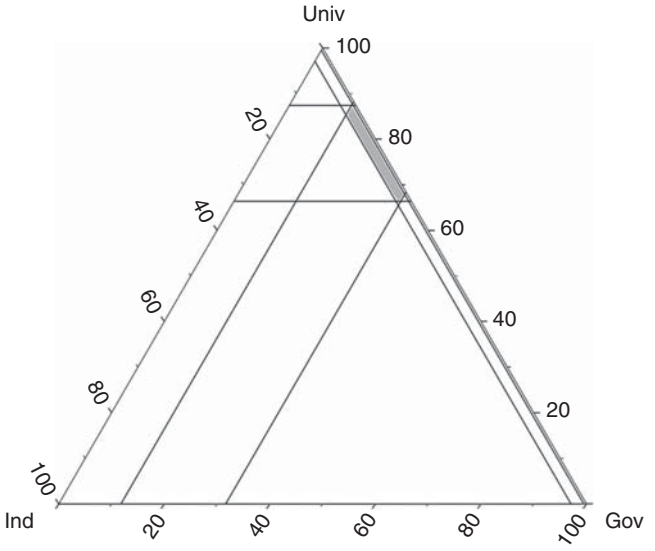


Figure 4.
Core of Nigeria

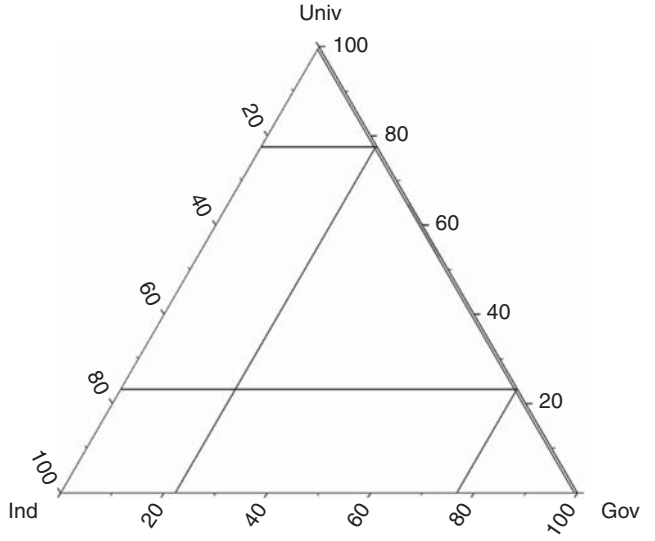


Figure 5.
Core of Burkina Faso

Shapley values and nucleoli

The Shapley values and nucleolus of the West African innovation systems are computed in Table IV. The Shapley value keeps the ranking of actors according to their output, e.g. where university is the biggest producer, it has the highest Shapley value followed by government and then by industry, and where government dominates the output, it has the highest Shapley value, followed by university and then by industry. That is not the case of

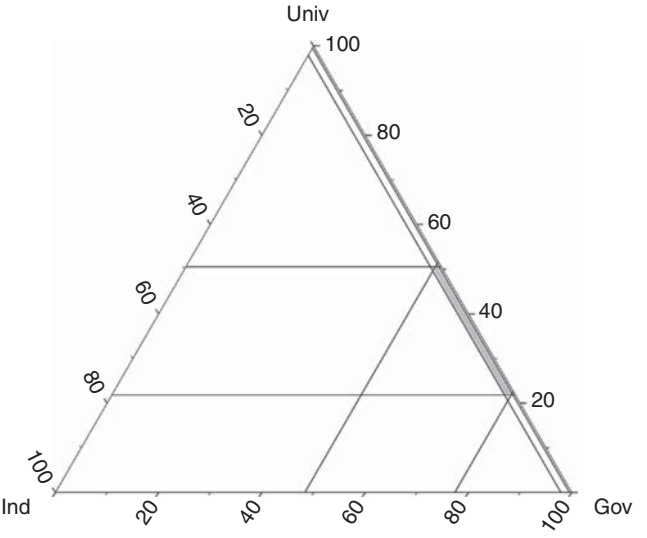


Figure 6.
Core of Senegal

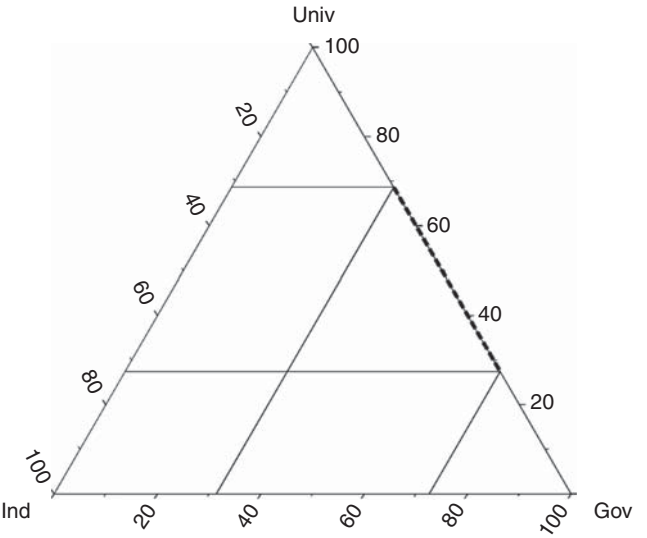


Figure 7.
Core of Liberia

the nucleolus: players are ranked in the same order whatever the country and the shares of actors are: university has the highest value followed by government and then by industry. Even where government dominates the output, it loses its advantage to the benefit of university. Compared to the Shapley value, the nucleolus allocated to government less than it does to university. Table IV also reveals, on the one hand, that university has more power in creating and leading to synergy in Nigeria than elsewhere, followed by Ghana and Sierra Leone, and on the other hand that government has more power to create and lead to synergy in Guinea Bissau than elsewhere followed by Guinea and Liberia.

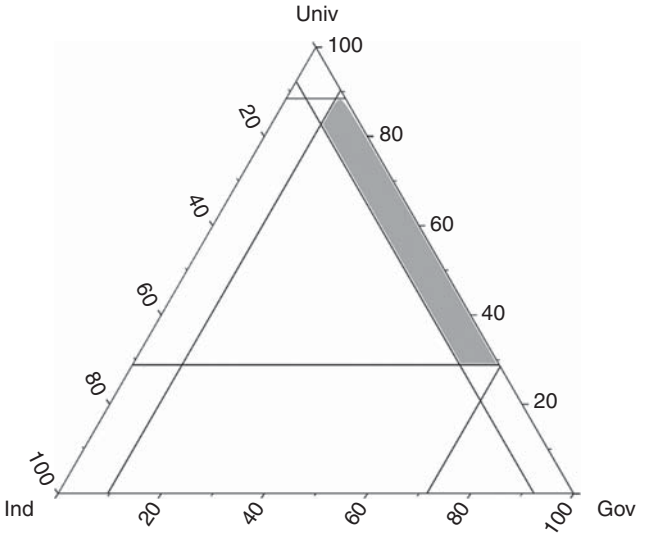


Figure 8.
Core of Cape Verde

Player		University	Industry	Government
Benin	Shapley value	55.87	0.29	43.84
	Nucleolus	79.43	0.34	20.23
Burkina Faso	Shapley value	50.31	0.31	49.28
	Nucleolus	77.21	0.34	22.45
Cape Verde	Shapley value	57.69	2.88	39.42
	Nucleolus	82.69	3.85	13.47
Cote d'Ivoire	Shapley value	55.31	0.17	44.52
	Nucleolus	74.52	0.27	25.21
Gambia	Shapley value	51.31	0.47	48.22
	Nucleolus	74.55	0.55	24.90
Ghana	Shapley value	63.29	1.5	35.66
	Nucleolus	83.23	1.21	15.56
Guinea	Shapley value	43.74	2.04	54.22
	Nucleolus	70.75	2.18	27.07
Guinea Bissau	Shapley value	25.77	0	74.23
	Nucleolus	50.22	0	49.78
Liberia	Shapley value	48.04	0	51.96
	Nucleolus	68.63	0.	31.37
Mali	Shapley value	54.25	0.58	45.17
	Nucleolus	78.01	0.84	21.45
Niger	Shapley value	48.49	0.09	50.42
	Nucleolus	70.05	0.08	29.87
Nigeria	Shapley value	84.16	0.58	15.26
	Nucleolus	92.72	0.62	6.66
Senegal	Shapley value	54.18	0.6	45.22
	Nucleolus	72.15	0.66	27.19
Sierra Leone	Shapley value	62.29	2.43	35.28
	Nucleolus	81.02	2.56	16.42
Togo	Shapley value	55.49	0.42	44.09
	Nucleolus	70.51	0.46	29.03

Table IV.
Shapley values and nucleoli of the Triple Helix system of selected countries

In order to give a meaning to the nucleolus, the difference between the nucleolus and the Shapley value of each actor should be computed (cf. Table V). This quantity is positive for the actor university in all countries, which means that the nucleolus is higher than the Shapley value for the actor university over all countries. In other words, university received more by the nucleolus than it expected by the Shapley value. This quantity is also positive for the actor industry in 13 countries and negative in 2 countries especially Ghana and Niger; however, it is negative for the actor government in all the selected countries. In summary, government shows solidarity towards the two other actors in all countries; it is joined by industry in Ghana and Niger.

Extent of synergy

We used the TU_game application provided by Caplan and Sasaki (2006) for computing the percentage the core makes as regarding the surface area of the ternary diagram. This quantity illustrates the share of all possible allocations of interests that guarantee the existence of synergy within the system. It ranges from 0 to 8.8 (Figure 9). The 15 countries may be categorised as follows: null surface area: Liberia and Guinea Bissau; surface area

	U	I	G
Benin	23.56	0.11	−23.61
Burkina Faso	26.9	0.03	−26.83
Cape Verde	25	0.97	−25.95
Cote d'Ivoire	19.21	0.1	−19.31
Gambia	23.24	0.08	−23.32
Ghana	19.94	−0.29	−20.1
Guinea	27.01	0.14	−27.15
Guinea Bissau	24.45	0	−24.45
Liberia	20.59	0	−20.59
Mali	23.76	0.26	−23.72
Niger	21.56	−0.01	−20.55
Nigeria	8.56	0.04	−8.6
Senegal	17.97	0.06	−18.03
Sierra Leone	18.73	0.13	−18.86
Togo	15.02	0.04	−15.06

Table V.
Difference between Nucleolus and Shapley value of actors of the Triple Helix system of selected countries

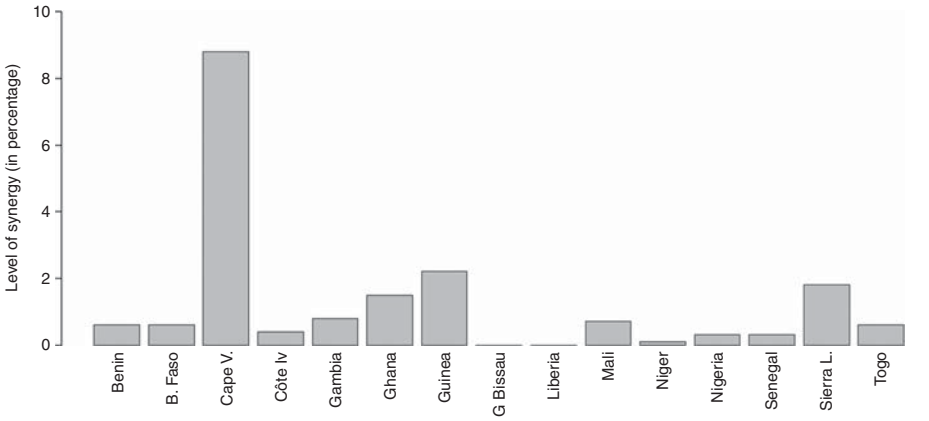


Figure 9.
Level of synergy within West African national innovation systems

less than 0.5: Cote d'Ivoire, Niger, Nigeria, Senegal; surface area greater than 0.5 but lower than 1: Benin, Burkina Faso, Gambia, Mali and Togo; surface area greater than 1 but lower than 2: Ghana, Guinea and Sierra Leone; and surface area greater than 2: Cape Verde.

Discussion

Biggest Triple Helix producer creates and lead to synergy; government and industry maintain synergy

Results presented in this study confirm the findings of Mêgnigbêto (2018a, b) according to which the biggest Triple Helix science producer has more power to lead to and create synergy However, whereas Mêgnigbêto (2018a, b) reported that only government maintains the synergy, this study adds industry as a second actor of synergy maintaining in both Ghana and Niger. In the Triple Helix theory, the term "government" does not reduce to an executive institution, but represents any public institution or power (Shinn, 2002a, b). Therefore, it should be understood as state, i.e. consisting of three distinct sets of powers, each with its assigned role: one is the legislature, whose role is to make the law; the second is the executive (sometimes referred to as "the government"), which is responsible for implementing the law; and the third is the judiciary, which is responsible for interpreting and applying the law (World Bank, 1997, p. 20). The traditional role of state is regulation: therefore, it is normal that government maintains synergy to favour innovation and hence economic growth and wealth creation. How can this role of industry be explained?

In the case of Niger, the explanation is straight forwards: industry produces nothing on its own but only one paper in collaboration. So, he expects 0.09 as utility (its Shapley value) but agrees to earn 0.08 (its nucleolus) in order the game continues; otherwise, no collaboration will occur and industry will keep its initial utility, e.g. nothing. In other words, the industry has interest that the game is played in order he earns 0.08. The same may apply to Ghana. However, the Ghanaian industrial sector performance as measured by the contribution to GDP and the domestic credit to private sector is higher than that of Niger over the period of study (World Bank, 2019), which may allow the industrial actor to make concessions in order to maintain synergy.

International collaboration may have influenced the position of the core

As Mêgnigbêto (2018b) found, we recorded three positions of the core on a ternary diagram; he concluded that the position of the core reflects the state intervention policy in the economy: capitalist countries where liberalism is the rule have their core positioned close to the university apex; socialism or communism countries where the state controls all the economic sectors have their core positioned close to the government apex and those that mix both systems have their core positioned at mid-way. The same mode of state intervention in the economy may have variants from one country to another; capitalism or socialism (or communism) in America, Europe or Asia is not the same in Africa (Sklar, 1988). In the case of West African countries, we hypothesise that this situation depends much on the dependence of science to foreign actors. Indeed, West African science is extraverted and influenced by external actors (Mêgnigbêto, 2013a). The average collaboration rate is about one half; but this indicator varies over countries: except Nigeria, the West African countries have an international collaboration rate higher than 70 per cent. Note that in this study, we take into account innovation actors that produce publications whatever their home country is. Even if West African states adopt STI policy documents, these policies are hardly implemented due to the lack of financials means. So science is directed by foreign actors; developing countries researchers help foreign countries to run their research agendas instead of working in the framework of the country's STI programmes. In 2016, 10 countries out of 15 have adopted at least once a STI policy, one has launched the process to adopt and four have nether elaborated an STI policy (Mêgnigbêto, 2016).

Industry's contribution is very limited

The output of industry is very limited in West Africa. Except Ghana (2 per cent), Guinea (3 per cent) and Cape Verde (7 per cent), industrial output is around 1 per cent or close to 0 per cent in the remaining countries. Let us note, however, that the Cape Verdean system produces less than one paper a month. In comparison, in USA, UK, Germany and France, the industrial share varies from 1 to 8 per cent; in India, Brazil, Russia and China, it varies from 0.23 to 4 per cent (cf. Mêgnigbêto, 2018b). This low performance of industry in science production in this part of the World is explained by hindrances (African Development Bank, 2011, pp. 3-8; ECOWAS Commission, 2010): strong presence of the informal sector; hard access to funding for investment in industry; hard access to efficient technologies (acquisition, maintenance); inadequate national markets; low competitiveness of existing industrial capacities and similarity of manufacturing activities; 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.); underutilisation of installed capacities illustrated by the fact that two-thirds of the industries operate at less than 50 per cent of their capacities; bureaucracy and corruption; and skill shortages and labour regulations.

Comparison with mutual information and transmission power

In this section, we compare rankings of selected countries with mutual information, transmission power and surface area of the core all three as indicators of the synergy within an innovation system (Table VI). We computed the Spearman rank correlation coefficient between mutual information, transmission power and surface area of the core for the 15 West African countries. This indicator is 0.85 for mutual information and transmission power, −0.015 for mutual information and surface area of the core, and 0.07 for transmission power and surface area of the core, leading to the conclusions that there is a strong correlation between the ranking with the mutual information and the transmission power on the one hand, but a weak correlation between the mutual information and surface area of the core, and transmission power and the surface area of the core on the other hand. Mutual information may be negative, null or positive. When it is negative, it indicates the existence and level of synergy; and when it is positive, it indicates the extent of the control State exerts on the considered innovation system (Leydesdorff, 2003). Transmission power is the

Table VI.
Ranking of selected countries according to mutual information, transmission power and surface area of the core

	Mutual information		Transmission power		Surface area of the core	
	Value	Rank	Value	Rank	Value	Rank
Benin	0.69	13	0.04	12	0.6	10
Burkina Faso	−3.55	7	3.53	6	0.6	9
Cape Verde	5.38	15	0.32	9	8.8	1
Cote d'Ivoire	−0.13	9	0.07	10	0.4	11
Gambia	−8.34	5	6.11	5	0.8	6
Ghana	−18.50	3	13.78	3	1.5	4
Guinea	−39.01	2	36.68	1	2.2	15
Guinea Bissau	0	11	0	14	0	2
Liberia	0	10	0	15	0	14
Mali	−1.93	8	1.52	8	0.7	7
Niger	0.82	14	0.05	11	0.1	13
Nigeria	−11.19	4	7.98	4	0.3	12
Senegal	−7.40	6	3.51	7	0.8	5
Sierra Leone	−58.59	1	34.51	2	1.8	3
Togo	0.05	12	0	13	0.6	8

Note: Data on mutual information and transmission power are extracted from Mêgnigbêto (2016)

normalisation of mutual information; it varies from 0 to 100 and indicates the strength of information flow within an innovation system (Mêgnigbêto, 2014a). Transmission power and mutual information are conceptually and methodologically related, that may explain the strong correlation mentioned above.

Conclusion

This paper sets as target the measurement of synergy within the Triple Helix innovation systems of the 15 West African countries using game theory. For this purpose, we used bibliographic data collected from Web of Science over a decade (2001–2010) and distinguished Triple Helix actors (university, industry and government) outputs and their bi- or trilateral collaborations. The core, the Shapley value and the nucleolus were used to characterise the synergy within the Triple Helix innovation systems. The innovation actor with the largest share to the whole production of a country has the highest Shapley value, and hence, has more power to create and lead to synergy. Government maintains synergy in all innovation systems and is joined in its efforts by industry in Ghana and Niger. There is synergy in all the selected innovations systems; however, its level varies from one country to another. The core is positioned differently according to the country due to the influence of foreign partners on the considered innovation system. The industrial sector's contribution is very limited due to hindrances to its development. The ranking of selected countries according to the level of synergy as measured by the core has no correlation with the one with the transmission power or mutual information.

Note

1. 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 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).

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