The Triple Helix of innovation as a double game involving domestic and foreign actors

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Abstract

Purpose: The collaboration relationships between innovation actors at a geographic level may be considered as grouping two separate layers, the domestic and the foreign. At the level of each layer, the relationships and the actors involved constitute a Triple Helix game. The paper distinguished three levels of analysis: the global grouping together all actors, the domestic grouping together domestic actors, and the foreign related to only actors from partner countries.

Design/methodology/approach: Bibliographic records data from the Web of Science for South Korea and West Africa breakdown per innovation actors and distinguishing domestic and international collaboration are analyzed with game theory. The core, the Shapley value, and the nucleolus are computed at the three levels to measure the synergy between actors.

Findings: The synergy operates more in South Korea than in West Africa; the government is more present in West Africa than in South Korea; domestic actors create more synergy in South Korea, but foreign more in West Africa; South Korea can consume all the foreign synergy, which is not the case of West Africa.

Research limitations: Research data are limited to publication records; techniques and methods used may be extended to other research outputs.

Practical implications: West African governments should increase their investment in science, technology, and innovation to benefit more from the synergy their innovation actors contributed at the foreign level. However, the results of the current study may not be sufficient to prove that greater investment will yield benefits from foreign synergies.

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Originality/value: This paper uses game theory to assess innovation systems by computing the contribution of foreign actors to knowledge production at an area level. It proposes an indicator to this end.

Keywords: Triple Helix; Game theory; Core; Shapley value; Nucleolus; South Korea; West Africa

1 Introduction

Collaboration in science has been studied at different levels (micro level that involves individuals, (ii) meso level with institutions, and (iii) macro level with countries or groups of countries, cf., Hou et al., 2008) with various techniques, e.g., social network analysis (e.g., Olmeda-Gómez et al., 2008), factorial analysis with techniques like author citation analysis (White & Griffith, 1981), information theory (e.g., Leydesdorff, 1991), game theory (e.g., Mêgnigbêto, 2018c), etc. Beyond knowledge production and sharing, collaboration in science allows authors to share expertise, data, equipment, methods, and techniques and improve their skills; they increase their productivity and the impact of their publications. Funding seeking, dissertations supervising, and network expansion are motivations for collaboration (cf., e.g., Bordons & Gomez, 2000; Katz & Martin, 1997; Toivanen & Ponomariov, 2011; Wagner, 2006). Collaboration in science has advantages; that is the reason why science, technology, and innovation policy documents on country, as well as continent level, encourage it (cf., for example, the Science, Technology, and Innovation Strategy for Africa (STISA-2024) Africa Union Commission, 2014).

The Triple Helix concept introduced by Etzkowitz and Leydesdorff (Etzkowitz et al., 2000; Etzkowitz & Leydesdorff, 1995) is one of the variants of the nonlinear model of innovation (Etzkowitz et al., 2000; Leydesdorff, 2012; Meyer et al., 2014); it postulates that the interactions between university, industry and government create synergy that leads to innovation (Leydesdorff & Etzkowitz, 2001). According to Mêgnigbêto (2018c), the Triple Helix of university-industry-government relationships is a three-person cooperative game with transferable utility; then, the core, the Shapley value, and the nucleolus were proposed to measure synergy within an innovation system.

To the best of our knowledge, few papers studied international co-authorship related to the Triple Helix; they are Choi et al. (2015), Leydesdorff and Sun (2009), Kwon (2011), Kwon et al. (2012), Shin et al. (2012) and Mêgnigbêto (2015, 2016). Apart from Choi et al. (2015), they all used mutual information (Leydesdorff, 2003)[①] or transmission power (Mêgnigbêto, 2014) as indicators; they mainly found that

[①] For a mathematic formulation and calculation of the mutual information, see Hu et al. (2021)

globalization has given opportunities for researchers to collaborate worldwide regardless the distance (Waltman et al., 2011); the mutual information has weakened in some countries and that international collaboration has strengthened knowledge sharing between innovation actors. But, apart from Mêgnigbêto (2015), authors did not quantify the synergy created by international actors to evaluate how it affected the one at the domestic level. Using game theory, Mêgnigbêto (2019) analyzed the positions on a ternary diagram of the cores of the 15 West African Triple Helix innovation games and suggested that international collaboration may have influenced them. Therefore, a question arises:" How can the effect of international collaboration on the synergy within a Triple Helix innovation system be assessed with game theory?"

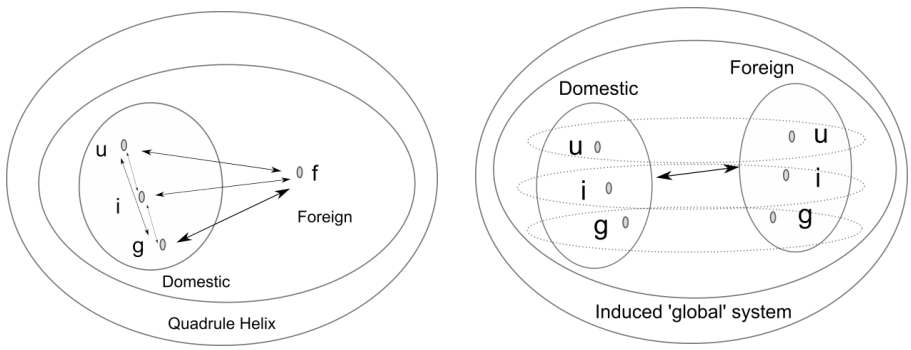
In this paper, we show that the Triple Helix innovation system in a geographic area is constituted of two layers of relationships, the one at domestic level and the other at the foreign level. Each constitutes a Triple Helix game that could separately be analyzed. The objective is threefold: 1) to show that a Triple Helix game, in a geographic area, groups together two games, the one at the domestic level and the other at the foreign level ii) to determine the rules and values of the game at each level, and iii) to assess the influence of the foreign game on the global one.

2 Method

2.1 Triple Helix relationships constituted of two layers

Contrary to Leydesdorff and Sun (2009), Kwon (2011) and Kwon et al. (2012) which considered all the innovation actors that intervened in a country's international as the "fourth helix", i.e., as if they were only one actor from the same geographical area, Shin et al. (2012) on the one hand, and Mêgnigbêto (2015, 2016) on the other hand, categorized actors considering the domestic level as one area and the foreign level as a second area (cf., Figure 1). By doing so, they considered a national innovation system as the superposition of two layers of relationships and actors, the domestic and the international (or foreign); the two layers "interact and exert on each other a mutual influence that may act on the synergy" at the global level (Mêgnigbêto, 2015, 2016). Let us individually consider each layer (its actors and their collaboration relations at the level): it is an entire Triple Helix relationship, so a game (Mêgnigbêto, 2018c); hence, the Triple Helix game at an area level may be analyzed as bringing together two games, the domestic and the foreign one, with the same actors (university, industry and government) that may play either at the domestic or at the foreign level. Mêgnigbêto (2024) showed that a Triple Helix of innovators game is convex; therefore, the global, domestic, and foreign (above-mentioned) games all are convex.

In this paper, we qualify the game of "double" to avoid any confusion with terms yet used in game theory like combined game, sum of games, or decomposable game. Firstly, according to Bloch and Huang (2013), a combined game involves exactly two players and, at least, two independent games; in the Triple Helix game, there are three players; so, these conditions are not fulfilled. Secondly, Block and de Clippel (2010) dealt with a combined game; they did not limit the number of players; besides, they equaled the combination and summation of games. In our opinion, their development is related to independent games involving the same actors, which is not the case of the domestic and the foreign Triple Helix game, because all the papers resulted from international collaboration, primarily, are co-authored domestically and, then, are also attributed to Triple Helix domestic actors. As an illustration, the core of the sum of two convex games is equal to the sum of the cores of the game (Bloch & de Clippel, 2010); the addition operates on the characteristic functions of the games and hence at the level of the analytic form of the cores.② This could not apply to the case of the Triple Helix domestic and foreign games; otherwise, one would reach a total number of papers higher than the number of publications within the system. Thirdly, Shapley (1965, 1971) stated that a convex game is decomposable (therefore, may split into its finest components) and demonstrated that a strictly convex game is indecomposable (see also González-Díaz & Sánchez-Rodríguez, 2008). Because a Triple Helix game where all the bilateral and the trilateral relationships exist is strictly convex (cf., Mêgnigbêto, 2024), it is indecomposable. In conclusion, neither the global Triple Helix game is the summation or the combination of the domestic and foreign Triple Helix games, nor the Triple Helix domestic and foreign games are components of the global Triple Helix game.



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

(b) Method used by Mêgnigbêto (2015) and also in this study

Figure 1. Methods for considering foreign actors in the study of the Triple Helix spheres' contributions to the Triple Helix relationships.

② "The coalitional function associated to the combined issues is simply the sum of the coalitional functions associated to each issue taken separately (Bloch & de Clippel, 2010, p. 2425)

2.2 Triple Helix game and indicators

This section introduces the rules of the Triple Helix game and the indicators of synergy used: the core, the Shapley value, and the nucleolus.

The three players of the Triple Helix game (university -u-, industry -i- and government -g) may play the game alone or with each other. Hence, the following coalitions may form: u, i, g, ui, ug, ig, and uig. Therefore, the characteristic function of the Triple Helix game, which attributes each coalition its payoff (publications share) is as follows (Mêgnigbêto, 2017, 2018c):

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

where U, I, and G represent the number of papers that university, industry, and government published on their own; UI, UG, and IG represent the number of papers university and industry, university and government, industry and government co-authored; and UIG represents the number of papers the three actors co-authored (Mêgnigbêto, 2017, 2018c).

The core expresses the existence and the extent of synergy. 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, 2018c):

$$\begin{cases} \upsilon(\mathrm{u}) \le \mathrm{x}_{\mathrm{u?}} \le \upsilon(\mathrm{uig}) - \upsilon(\mathrm{ig}) \\ \upsilon(\mathrm{i}) \le \mathrm{x}_{\mathrm{i?}} \le \upsilon(\mathrm{uig}) - \upsilon(\mathrm{ug}) \\ \upsilon(\mathrm{g}) \le \mathrm{x}_{\mathrm{g?}} \le \upsilon(\mathrm{uig}) - \upsilon(\mathrm{ui}) \\ \mathrm{x_u} + \mathrm{x_i} + \mathrm{x_g} = \upsilon(\mathrm{uig}) \end{cases} \quad (2)$$

The core of a Triple Helix game exists, provided that there is output within the system (Mêgnigbêto, 2024); when all the bilateral and the trilateral relations exist within the Triple Helix innovation system, the game is strictly convex and the core is a hexagon, hence, its surface area could be used as a measure of the synergy within a Triple Helix innovation system (Mêgnigbêto, 2024).

The Shapley value represents the strength of a player to create and lead to synergy; it is the triplet S_u, S_i, S_g for the players, university, industry, and government

respectively, so that (Mêgnigbêto, 2018c):

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

The nucleolus is the efforts of solidarity made by an actor (and its partners) to maintain synergy within the innovation system (Mêgnigbêto, 2018c); it has no analytic formula and is hard to compute (Sziklai, 2015); therefore, we used a software application to this end.

2.3 Data

The data we analyzed below (Table 1) come from Mêgnigbêto (2015) who downloaded bibliographic records of South Korea and the West African region[③] from Web of Science and breakdown according to the Triple Helix actors and their bi- or trilateral collaboration on the one hand, and according to the origin of actors (domestic or international) on the other hand.

Table 1. Triple Helix sectors output in West Africa and South Korea (2001-2010).

			U	I	G	UI	UG	IG	UIG	Total
South Korea	Global	#	228,643	3,504	42,215	7,522	68,703	1,293	2,463	354,343
		%	64.53	0.99	11.91	2.12	19.39	0.36	0.70	100
	Domestic	#	241,195	4,092	49,873	6,262	46,801	1,116	1,547	350,886
		%	68.74	1.17	14.21	1.78	13.34	0.32	0.44	100
	Foreign	#	49,102	595	9,320	623	11,262	200	380	71,482
		%	68.69	0.83	13.04	0.87	15.76	0.28	0.53	100
West Africa	Global	#	17,062	54	3,922	123	8,129	34	112	29,436
		%	57.96	0.18	13.32	0.42	27.62	0.12	0.38	100
	Domestic	#	17,977	79	6,605	61	2,887	14	8	27,631
		%	65.06	0.29	23.90	0.22	10.45	0.05	0.03	100
	Foreign	#	7,069	51	2,485	37	3,212	23	58	12,935
		%	54.65	0.39	19.21	0.29	24.83	0.18	0.45	100

③ 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. They all are members of the Economic Community of West African States (ECOWAS), a regional integration community.

3 Results

3.1 Sectorial output

In both South Korea and West Africa (Figure 2), for the global output, university is the biggest science producer, followed by government and then by industry. As far as the bilateral collaborations are concerned, university-government comes first, followed – in this order - by university-industry and then by industry-government. The trilateral relations are registered within the two areas. The percentage shares of the Triple Helix spheres are higher in the case of South Korea than that of West Africa, except for government (G) on the one hand, and university-government (UG) on the other hand. The South Korean Triple Helix spheres are the biggest producers as compared with the West African, both at domestic and foreign levels, except for government (G) at the domestic level and government and university-government at the foreign level.

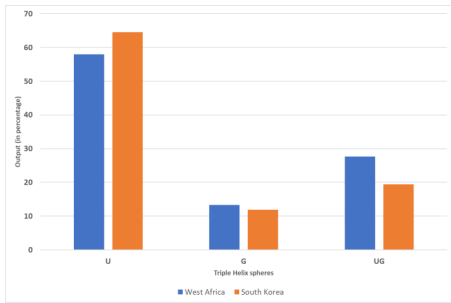
For both areas, whatever the sectorial output is, the domestic share is higher than the global one for the Triple Helix actors but lower for their bi- or trilateral combinations. The comparison of output by Triple Helix spheres and between the two areas reveals that university's share is higher in South Korea than in West Africa at the three levels (global, domestic, and foreign) but that government and its bi-lateral collaboration with university have higher values in West Africa than in South Korea at all the levels. In the same vein, South Korean Triple Helix spheres have output higher than the one of West Africa for industry and its bi or trilateral collaborations.

3.2 Characteristic functions of the games

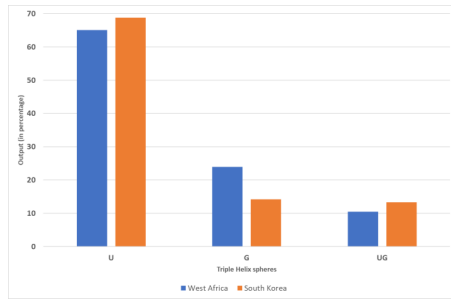
The characteristic functions of the considered games are presented in Table 2. They show that i) the ranking of coalitions according to their utilities, in decreasing order, is ug, ui, u, ig, g, i; ii) in South Korea, at the foreign level, u, i, g and ui have utilities lower than the ones at domestic level but higher than the ones at global level, except for ug and ig; but no order could be observed in the case of West Africa; iii) at the three levels (global, domestic and foreign), coalitions involving g (g, ug and ig) have utilities greater in West Africa than in South Korea; and, iv) the utilities of the three coalitions u, i and ui are lower in West Africa as compared with those in South Korea; this may be interpreted as the consequence of the greater share the actor g has in West Africa, as compared to the one it has in South Korea. In West Africa, foreign i has the highest utility, followed by the domestic i, and the global i; in South Korea, the domestic i has the highest utility followed by the global i and, then, the foreign i.

Table 2. Characteristic functions of the games.

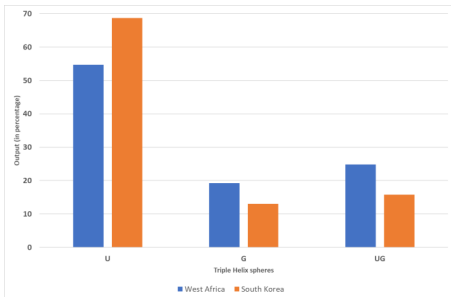
		u	i	g	ui	ug	ig	uig
South Korea	Global	64.53	0.99	11.91	67.64	95.83	13.27	100
	Domestic	68.74	1.17	14.21	71.69	96.29	15.70	100
	Foreign	68.69	0.83	13.04	70.40	97.48	14.15	100
West Africa	Global	57.96	0.18	13.32	58.56	98.90	13.62	100
	Domestic	65.06	0.29	23.90	65.57	99.41	24.24	100
	Foreign	54.65	0.39	19.21	55.33	98.69	19.78	100



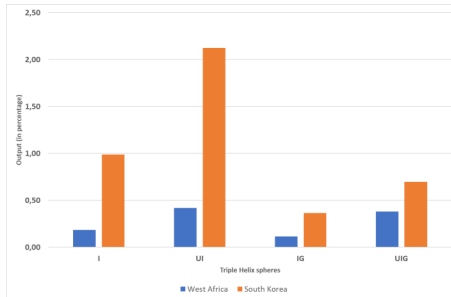
(a) U, G and UG for global output



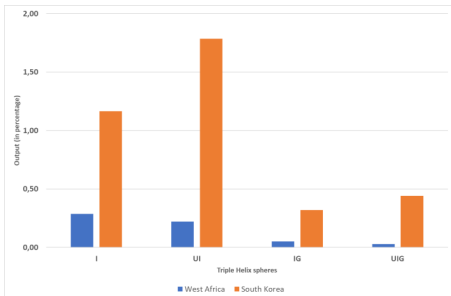
(b) U, G and UG for domestic output



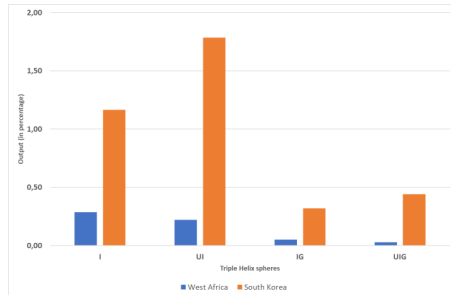
(c) U, G and UG for foreign output



(d) I, UI, IG and UIG for global output



(e) I, UI, IG and UIG for domestic output



(f) I, UI, IG and UIG for foreign output

Figure 2. Triple Helix sectors output in West Africa and South Korea (2001-2010).

3.3 Cores

Table 3 gives the analytic form and the surface area of the cores of the games; the surface area is expressed as a percentage of the one of the triangle supporting the ternary diagram. The core of a cooperative game normally is plotted on a ternary diagram; however, to better visualize the relative positions of the three cores of each innovation system, we present below a zoomed version of them (Figure 3 and Figure 4), regardless of the supporting triangle.

Table 3. Analytic form and surface area of the cores.

		Global	Domestic	Foreign
South Korea	Analytic form	$\begin{cases} 64.53 \le x_u \le 86.73 \\ 0.99 \le x_i \le 4.17 \\ 11.91 \le x_g \le 32.36 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 68.74 \le x_u \le 84.30 \\ 1.17 \le x_i \le 3.71 \\ 14.21 \le x_g \le 28.31 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 68.69 \le x_u \le 85.85 \\ 0.83 \le x_i \le 2.52 \\ 13.04 \le x_g \le 29.60 \\ x_u + x_i + x_g = 100 \end{cases}$
	Surface area	1.288	0.709	0.552
West Africa	Analytic form	$\begin{cases} 57.96 \le x_u \le 86.38 \\ 0.18 \le x_i \le 1.09 \\ 13.32 \le x_g \le 41.44 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 65.06 \le x_u \le 75.76 \\ 0.29 \le x_i \le 0.59 \\ 23.90 \le x_g \le 34.43 \\ x_u + x_i + x_g = 100 \end{cases}$	$\begin{cases} 54.65 \le x_u \le 80.22 \\ 0.39 \le x_i \le 1.31 \\ 19.21 \le x_g \le 44.67 \\ x_u + x_i + x_g = 100 \end{cases}$
	Surface area	0.515	0.063	0.464

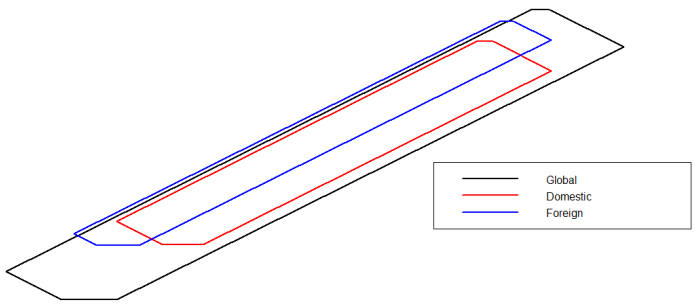


Figure 3. Cores of the South Korean games.

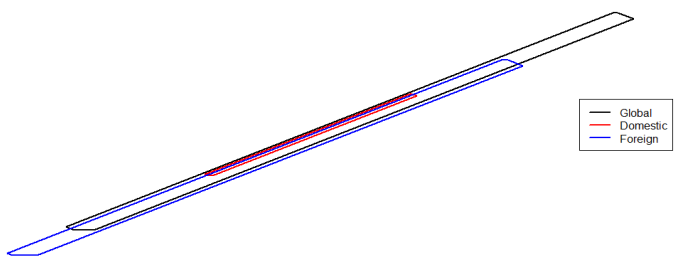


Figure 4. Cores of the West African games.

Figure 3 shows that the South Korean global core is the lengthiest, the widest, and the largest as compared to the domestic and foreign cores. The foreign core is entirely included within the global core, but slightly moves backward, as a consequence of the difference between the lower bounds of inequalities related to the actor in the analytic form of the core at the global and the foreign level (0.99 and 0.83); the domestic and the foreign cores overlap. The West African cores depict another configuration: the domestic core is the thinnest, included within the global core - as in the case of South Korea - and positions on the border of the global core contrary to the case of South Korea; it also overlaps with the two other cores. The foreign core has a form similar to the one of the global core, except that a slip intervenes to the right; so that the global core starts first and ends while the foreign core continues. This slip, at both the start and the end, is the consequence of the larger value of the lower and upper bounds to the actor g's interests at the foreign level as compared to the ones of the same actor at the global level. Because the slip at the start is longer than the one at the end, the global core is the longest.

Table 3 also provides the surface area of the cores at all levels and for both areas. All the South Korean cores are larger than the West African ones. At each geographic area level, the global core is the largest. The South Korean domestic core is larger than the domestic one, but the reverse occurs in the case of West Africa. The surface area of the core depends on the contribution of each actor to its formation (Table 4) which is the difference between the upper and lower bounds to their utility in the analytic form (Mêgnigbêto, 2018c). Actor i has the lowest value, as a consequence of its lowest payoffs through the games at the three levels, which is also the consequence of its lowest share in the research output considered in this study (publications). In both areas, the contribution of an actor at the global level is larger than the one at the domestic or foreign level, which indicates that the core at the global level is as long or wider as the cores at the domestic and foreign levels, and consequently, that the association of the games gives more margin to create synergy at the national level. The difference in the contributions of actors u and g at all the levels are given in Column $\frac{(u-g)\times 100}{u}$, Table 4; we adopted the rule that a variation less than 5% is considered unmeaningful and concluded: in the case of West Africa, whatever the level, actors u and g have similar contributions to the formation of the core; for South Korea, this occurs only at the foreign level.

The games studied are all strictly convex; thus, each core has the form of a hexagon (Mêgnigbêto, 2024). The width is mainly determined by the contribution of the actor i and the length by the contributions of both u and g (Table 4) (Mêgnigbêto, 2018c, 2018b, 2019). For each polygon, the two parallel shortest sides are the ones engendered by the upper and lower bounds to actor u interests.

Table 4. Contributions of players to the formation of the cores.

		u	i	g	$\frac{(u-g)\times 100}{u}$
South Korea	Global	22.21	3.38	20.45	7.92
	Domestic	15.56	2.54	14.10	9.38
	Foreign	17.16	1.68	16.57	3.44
West Africa	Global	28.41	0.91	28.11	1.06
	Domestic	10.70	0.30	10.53	1.59
	Foreign	25.57	0.91	25.46	0.43

3.4 Shapley values and nucleoli

The Shapley values and the nucleoli (see Table *5*) are obtained by using the package 'Game theory' (Cano-Berlanga et al., 2017) for the R statistical software (R Development Core Team, 2023).[④] In both areas and at all three levels, both the Shapley value and the nucleolus ranked university first, followed by government second, and industry third; these results conform to the findings by Mêgnigbêto (2018c, 2018b, 2019). Whereas in South Korea, university at the foreign level has the highest value as compared with the university share at the global and domestic levels, followed by the domestic level and the global level at the rear, the order is exactly the reverse in West Africa: university at the global level is at the top, followed by the domestic level and the foreign. The Shapley values differently ranked actors in industry and government across the levels. The nucleolus operates like Mêgnigbêto (2018c, 2018b, 2019) found: it increases the utilities of the university and industry actors to the detriment of the government.

Table 5. Shapley values and nucleoli of the games.

		Shapley value			Nucleolus		
		u	i	g	u	i	g
South Korea	Global	75.52	2.47	22.02	83.92	2.58	13.50
	Domestic	76.45	2.37	21.19	82.08	2.44	15.48
	Foreign	77.18	1.59	21.23	84.44	1.68	13.89
West Africa	Global	72.11	0.58	27.32	85.58	0.64	13.78
	Domestic	70.41	0.44	29.16	75.51	0.44	24.05
	Foreign	67.36	0.78	31.87	79.49	0.85	19.67

④ Mêgnigbêto (2018c, p. 1124) warmed that nowadays, even there exist many software applications to compute the nucleolus, they do not always yield the same results with the same data, due to common mistakes on the process (Guajardo & Jorusten, 2015); therefore, he used the 'Game theory' package of the R statistical software. We used other software applications and found different values of the nucleolus each time; for example, the nucleolus of u decreases at a lesser extent and the one on i and g increase at a lesser extent as compared respectively to their Shapley values.

5 Discussion

In this paper, we considered the Triple Helix of innovation in a geographic area (the global system) as composed of two layers of relationships, the domestic and the foreign ones. To study the effect of international collaboration on the national innovation system, we compared the domestic game to the global one. By doing so, we assumed that if domestic innovators acted solely, i.e., without foreign actors, the national innovation game would be reduced to the domestic one, i.e., to the production of the domestic actors; the contribution of international innovators, therefore, engendered the global innovation system which is different from the domestic one.

5.1 Synergy operates more in South Korea than in West Africa

Everywhere, u and i are the one-person coalitions with the biggest and lowest utilities respectively; the two-person coalition ug has the highest utility when the grand coalition is not considered; these results conform to the findings of Mêgnigbêto (2018c, 2018b, 2019) and is the consequence of the share these actors have in the scientific output of the considered areas (cf., for example, Leydesdorff, 2003; Leydesdorff & Sun, 2009; Mêgnigbêto, 2013b). The limited contribution of actor i to the formation of the core as compared to the ones of u and g is due to the nature of the research output considered, i.e., publications. However, i) the contribution of i in South Korea is two- to eight-fold the one in West Africa; and the core of South Korea is wider, about fourfold the one of Africa at the global level. Blom et al. (2016) provided the following explanation: the transitory nature of many researchers in Sub-Saharan Africa may prevent researchers from building relationships with African firms and governments, reducing the economic impact and relevance of research.

5.2 Government is more present in West Africa than in South Korea

The relatively higher share of government in the West African output as compared to South Korea may be explained, firstly, by the specialization of African science in *Agricultural and veterinary sciences* and *Medical and health sciences* to the detriment of other fields of science (cf., for example, Arvanitis et al., 2000; Blom et al., 2016; Chuang et al., 2011; Mêgnigbêto, 2021; Pouris & Ho, 2014; Pouris & Pouris, 2009), and secondly, - consequently - the heavy involvement of African governments in the health sector and the many national and international health-related initiatives on-going on the continent through collaborative programs (African Observatory of Science, Technology and Innovation, 2014) Africa. Let us recall that Mêgnigbêto (2013b, 2016) found that West African governments specialize in Medical and health sciences.

5.3 Domestic actors create more synergy in South Korea but foreign ones in West Africa

We also found that, for each geographic area, the core of the global game is the widest, the lengthiest, and the largest of the considered three cores. The South Korean global core would have a surface area of 0.709 (the one of the domestic core), but thanks to international collaboration, its surface area rises to 1.288, which means that South Korea gains 82% of its synergy from international relationships; West Africa would have a core of whose surface area is 0.068, but international collaboration made it rises to 0.515, so an increase of more than sevenfold. According to Mêgnigbêto (2018c, 2019), 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 the existence and level of synergy within a Triple Helix innovation system. Therefore, the following interpretations hold. I) The domestic innovation system in South Korea creates more synergy than the one of West Africa; in other words, the South Korean innovation system is more self-organized (Leydesdorff, 2003, 2010) and autonomous than the West African one; as the surface area of the core expresses the margin actor has to build coalitions, and then to negotiate, this result confirms the one by Mêgnigbêto (2015) according to which, the South Korean innovation system is more integrated by itself than the West African one. II) The synergy created by foreign innovators is higher than the one by the domestic innovators in West Africa, but the reverse is true for South Korea; this illustrates the high level of dependence of the West African science toward abroad (cf., e.g., Mêgnigbêto, 2013a; Wagner, 2006). The South Korean situation was recorded by Mêgnigbêto (2015, 2016, 2018a); indeed, the country has strengthened its national innovation system after years of benefiting from international collaboration, as a consequence of changes in its policies over decades (cf., Kwon et al., 2012). And III) The West African innovation system better benefits from foreign contributions than South Korea; indeed, international collaboration brings national innovators the opportunity to enlarge their partnerships; globalization is one of the factors. This finding is one of the motivations for international research collaboration according to the literature. The fact that the Triple Helix game is always convex - e.g., it guarantees increasing returns in case of collaboration - may explain this, as well.

5.4 South Korea entirely consumes foreign synergy, not West Africa

The sum of the surface area of the cores of the domestic and international games is different from the one of the global game: it is lower in the case of South Korea and higher in the case of West Africa. This indicates that the South Korean innovation

system entirely consumed the synergy the collaboration with foreign actors produced, but the West African did not. The case inspires an indicator of capacity of foreign synergy consumption by an innovation system. If S_g, $S_{d,}$ and S_f respectively denote the extent of the synergy (the surface area of the cores) at the global, domestic, and foreign levels, the foreign synergy consumption capacity index (which is higher than or equal to 0 and may be expressed as a percentage) is:

$$\varsigma = \frac{S_g - S_d}{S_f} \tag{4}$$

If the foreign synergy consumption capacity index is lower than 100 (or 1), it indicates that the considered area entirely did not consume the synergy its foreign actors had contributed, or that foreign actors produced synergy more than the area needed; there is a share of the synergy produced within the system that is useless, maybe irrelevant; in other words, the area innovation system has not the capacity to consume the synergy its domestic actors produced in collaboration with their foreign partners.

If the foreign synergy consumption capacity index equals 100 (or 1), it indicates that the considered area's foreign actors have produced the exact quantity of synergy it needed; in other words, foreign actors have contributed to complement domestic actors' efforts to reach the level of synergy the innovation system required.

If the foreign synergy consumption capacity index is higher than 100 (or 1), it indicates that the considered area consumed more than the synergy its foreign actors had contributed. How could this happen? According to François (2004), "Synergy is the fusion between different aims and resources to create more between the interacting parties than they had before the interactions (…). An object shows synergy when examining one of various of its parts (or even each one of them) separately, it is impossible to explain or predict the whole's behavior". In other words, on the one hand, domestic actors collaborated to create synergy at their level, so did foreign actors on the other hand; these 'two synergies' created at the first order, "combined" at a higher order to create a synergy to reach the level of synergy required by the innovation system.

In the case of South Korea, ς = 105.11%, and in the case of West Africa, ς = 97.41% which expresses that the South Korean innovation system can entirely consume the synergy contributed by its partners at the international level (and doing so creates a higher order synergy) but the West African does not. To better understand the index, two other ratios are required: $\frac{S_d}{S_g}$ and $\frac{S_f}{S_g}$ indicating respectively the share of the global synergy domestic and foreign synergies represent each. The first equals

55.05% in the case of South Korea and 12.23% in the case of West Africa, and the second equals 42.88% in the case of South Korea and 90.10% in the case of West Africa. The interpretation follows: domestic actors produced 55.05% of the synergy the South Korean innovation system required and foreign actors 42.88%; domestic actors produced 12.23% of the synergy the West African innovation system required and foreign actors 90.10%, which illuminates the higher dependence of the West African innovation system to abroad (cf., e.g., Adams et al., 2014; Bordons & Gomez, 2000; Mêgnigbêto, 2013a, 2021, 2023; Pouris & Ho, 2014), as a signal of a lack of internal research capacity and the critical mass to produce international quality research on its own (Blom et al., 2016).

6 Conclusion

In this paper, we showed that a Triple Helix of innovation game at a geographic area level may be considered as the sum of two games, the first involving domestic innovators and the second international innovators. We illustrated it by considering South Korea and West Africa's innovation systems over the decade 2001-2010 with publications as the unit of measurement of activities. We found that i) the synergy operates more in South Korea than in West Africa, indeed, the South Korean global core is twice the one of West Africa ii) government is more present in West Africa than in South Korea; its utility and the one of the coalition it forms with university are higher in West Africa than in South Korea; iii) domestic actors create more synergy in South Korea but foreign actors more in West Africa: the core at the domestic level is larger in South Korea than in West Africa, and, iv) South Korea can consume all the foreign synergy, which is not the case of West Africa: in South Korea, the surface area of the global core is higher than the sum of the surface areas of the domestic and foreign cores, but the reverse in West Africa.

In fact, the profile of West Africa (as compared to South Korea) is the consequence of the problems of science, technology, and innovation in the region and are better synthesized as follows (Mêgnigbêto, 2016). West African countries' GERDs are far from the target of 1%, but South Korea has a GERD of more than 3.75% in 2010 (end of the period under study). The hindrances to the development of science, technology, and innovation in West Africa, could not allow speaking of the existence of an innovation system at the regional level. At individual countries' level even, "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; Mouton & Waast, 2008, 2009). West Africa lacks human resources and research is mainly funded by foreign donors; so, the region's research institutions and researchers help more in the execution of the activities

under the agendas of partners 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). In general, developing countries imitate developed ones "rather slavishly and uncritically" (Mouton, 2007; Mouton & Waast, 2008, 2009) but cannot always act like them.

Competing interest statements

The author is a member of the editorial board of the journal.

Data availability statements

Data analyzed in this study are taken from Mêgnigbêto (2015), an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/).

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