Identifying the configurations leading to the central position in the inter-country research collaboration network: Evidence from tracking configurations over time with fsQCA

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Abstract

During the last two decades, less than 10% of countries have had the necessary capacities for high participation in international research activities. These countries have occupied central positions in the inter-country research collaboration network. This study, using the theoretical framework of the social system, tried to understand which subsystems were involved in achieving the central position. Based on the theoretical model of the research, an empirical study was conducted using fuzzy-set Qualitative Comparative Analysis (fsQCA) to identify the political, economic, social, and cultural factors that simultaneously led to the central position in the inter-country research collaboration network from 2002 to 2017. Data was analyzed through two novel methodological strategies: fuzzy-set ideal type analysis and strategy of multiple periods, single fsQCA. The results indicated the existence of twenty types of central countries and four causal configurations leading to the central position. This study concludes that in liberal democratic states, at least two political and economic subsystems exist. In non-liberal democratic states, at least three political, economic, and social subsystems must intervene to achieve the central position. By identifying causal configurations leading to the central position through the social system framework and strategies of tracking configurations over time with fsQCA, this study contributes to the literature on international research collaboration. It also offered suggestions to improve the semi-peripheral countries' position.

Keywords: Inter-Country Research Collaboration (IRC), Co-Authorship Network, Central Position, Configuration, Fsqca.

Introduction

Research collaboration at the country level reflects research cooperation between nations

(or international cooperation) (Katz & Martin, 1997; Lu & Ma, 2017). In the history of science, isolated scientific societies have never enjoyed scientific superiority (Mali, Kronegger, Doreian & Ferligoj, 2012). That is why the globalization of science has led to the rapid transition from traditional cosmopolitan individualism of science to transnational collectivism (Ziman, 1994). This transfer implies that science as a social system is a community-based social activity with a relational foundation (Mali et al., 2012). When discussing science as a social system, we must remember that social systems are not unrelated. Parsons (1991) argues that the development of other social systems influences scientific development. This means that social systems interact with each other. The science system is no exception to this rule and is influenced by extra-scientific factors (Subramanyam, 1983).

Today, it is clear that *world system* theory also applies to the world system of science (Schubert & Sooryamoorthy, 2010). Wallerstein (1974) initially proposed this theory to illustrate the unequal exchanges in the global economic system. According to this theory, the Inter-country Research Collaboration (IRC) network, like the global economic exchanges network, has a core-periphery structure (Schubert & Sooryamoorthy, 2010; Choi, 2012; Gui, Liu & Du, 2019; Gu & Liu, 2020). A prominent feature of such a structure is preferential attachment (Wagner & Leydesdorff, 2005). According to this feature, less than 10% of countries have high degrees of research collaboration (Gui et al., 2019). A high degree means being in a central position of the IRC network, and a low degree means being in a peripheral position (Borgatti & Everett, 2000).

The IRC network has evolved from a bipolar world, centered on North America and Europe, to a tri-polar world, centered on North America, Europe, and Asia-Pacific (Heimeriks & Boschma, 2014; Gui et al., 2019). The Asia-Pacific pole has been formed due to the significant growth of research collaborations in some Asian countries, especially China, and has played a role in the gradual decentralization of the network (Gui et al., 2019). This means that some countries have improved their position in the IRC network over time.

Many studies identified the role of extra-scientific macro-level factors such as geography, economics, and language. These studies found similarities or dissimilarities in which factors can foster or hinder the IRCs. However, the fact that some countries have occupied different positions in the IRC despite their similarity in one or more factors has not yet been considered. For example, Gui et al. (2019) found that English-speaking countries are more likely to collaborate scientifically. Nevertheless, according to their findings, not all English-speaking countries are necessarily in the same position. This study will show why a few countries have occupied the central position. Also, it will show why some countries could be promoted to a central position (such as China), but others could not.

Most of the above studies tried to recognize the extra-scientific macro-level factors by regression. The regression models consider the effect of factors independently. This study will show the presence or absence of factors simultaneously leading to a central position in the IRC network over time. For this reason, the fuzzy-set Qualitative Comparative Analysis (fsQCA) was used to track the causal configurations over time. Therefore, the primary purpose of this study is to identify the causal configurations that lead to the central position in the IRC network over time. A configuration combines causal conditions leading to a particular outcome (Ragin, 2000). In this study, the outcome is the central position in the IRC network. It is characterized by a high degree of research collaboration. The degree is the number of research collaborations of each country with other countries. By adopting Parsons' *social system* theory and using

fsQCA, we seek to identify causal combinations of extra-scientific macro-level factors that lead to a central position in the IRC network. In addition, a descriptive attempt also has been made in line with a typology of central countries using fsQCA tools.

Literature Review
Theoretical Framework: The Social System

The theoretical framework of this study is based on Parsons' *social system* theory. The systemic approaches do not consider the effect of factors independently. Instead, they seek a holistic understanding of reality (Gharajedaghi, 2011). In holistic terms, society is a whole that has components (Baxter, 1993; Akerlof, 2002). These components interact with each other (Chalabi, 2002). Similarly, the main idea of Parsons' (1991) social system theory - known as the AGIL model - is to consider society as a total social system consisting of four subsystems: politics, economics, societal community (or social), and culture, each of which they have functions. The functions are adaptation of society (economics), goal attainment (politics), integration (social), and latent-pattern maintenance (culture). The advantage of the AGIL scheme is that it avoids political and economic reductionism (Esping-Andersen, 1990, 1999; Schröder, 2013). Instead of reducing society to politics or economics, Parsons considers these two to be merely two subsystems of society that can function in the presence of other subsystems.

From the perspective of Parsons' systematic approach to identifying the causes of an event, the impact of all four subsystems must be considered simultaneously. This means that in the case of the factors affecting a particular country's position in the IRC network, we must consider a combination of factors whose presence or absence simultaneously (not independently) leads to that country being in a particular position. Causal complexity occurs when countries are exposed to a single outcome from different configurations (Verweij & Vis, 2021). Increasing the number of configurations makes it difficult to identify causal configurations. Researchers can now identify these configurations using fuzzy-set Qualitative Comparative Analysis (fsQCA). This method provides tools to reduce the number of configurations to several main paths (causal configurations).

Subsystems of a social system and factors related to the countries' central position in the IRC network

This section will use a theoretical body to explain through what factors each subsystem of a social system overshadows the countries' central position in the IRC network. This study uses macro theories of development, international relations, and network theory to extract the factors related to each subsystem. These theories were selected for four reasons: (1) the analysis level of this study is macro; (2) it is placed in the realm of studies related to development (i. e., scientific development); (3) it looks at research collaboration as a kind of cooperative relationship between nations; (4) it pays attention to research collaboration in the form of a network. Since many causal conditions in comparative studies make it difficult to interpret the results (Fainshmidt, Witt, Aguilera & Verbeke, 2020), Ragin (2009) suggested that the number of conditions in fsQCAs ranges between three and eight. Hence, in this study, two conditions for each subsystem and eight conditions have been considered.

Political Subsystem

The first political factor is the political system (or regime type). Coppedge et al. (2011) and Merton (1973) argued that liberal democracy provides requisite conditions for scientific development. This is because it preserves scientists' right to free expression and allows them to communicate with scientists across political borders (Coppedge et al., 2011). Whetsell (2023) also found that liberal democracy has a positive and significant effect on the formation, persistence, and strength of international research collaboration. In addition, he found that countries with similar levels of liberal democracy are more likely to collaborate and maintain collaborative ties. The most apparent internal characteristics of a liberal democratic state are elections, separation of powers, due process, human rights, and the rule of law (Falk, 2002, p. 75). Usually, such states extend their liberal orientation to international relations and support increased international cooperation through institutional arrangements (Falk, 2002, p. 75). According to international cooperation theories (Badie, Berg-Schlosser & Morlino, 2011), increased cooperation between liberal democratic states reduces uncertainty and increases mutual trust among states, and thus, world peace (also known as *'democratic peace'*). Therefore, the extent to which countries have achieved a liberal democratic government can play a vital role in developing their research collaboration network. However, as Merton (1973) also stated, the influence of liberal democracy on scientific development cannot be described as a simple causal relationship, and other factors should be considered.

The second political factor is government effectiveness. According to the international cooperation theory, cooperation between nations depends on international factors and domestic institutions (Leeds, 1999). As a domestic political institution, the government can increase/decrease the likelihood of international research collaborations (Vieira, Cerdeira & Teixeira, 2022; Whetsell, 2023). Government policies can limit information dissemination (Vieira et al., 2022). For example, one view may favor free access to information, and another may advocate restrictions or censorship (Dawes, Gharawi & Burke, 2012). The rules, laws, and legal systems governing intellectual property and infrastructure are tools that can foster/hinder the learning and knowledge-sharing process (Boschma, 2005; Dawes et al., 2012). A government that guarantees intellectual property rights provides a platform for interactive learning (Boschma, 2005). Vieira et al. (2022) found that the countries with more distance in each dimension of quality of government (including voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, the rule of law, and control of corruption) have less collaboration with each other. However, they found that the negative effect of government effectiveness increased over time more than the different dimensions. Hence, countries with more efficient governments appear more likely to facilitate international research collaborations.

Economic Subsystem

The first economic factor is human development. After the first Human Development Report in 1990 (UNDP, 1990), arguments in development theory that considered human beings rather than money at the heart of development mainly were accepted. Human development, as an economic factor (Parreira, Machado, Logares, Diniz-Filho & Nabout, 2017), has a positive relationship with the scientific collaborations between countries (ibid) and the scientific products of countries (Stocks, Seales, Paniagua, Maehr & Bruna, 2008). Marinho, Campelo, França & Araujo (2017) argued that increasing education - as one of the indicators of human

development - plays a fundamental role in the search for knowledge to increase productivity. People with more knowledge and skills are better able to access information (Sahabi et al., 2012). Knowledge capital is a function of human development (Sota, 2013). In general, new knowledge is more diffused in regions with high human development (Marinho et al., 2017).

The second economic factor is exported value. Today, there is considerable emphasis on the belief that there is an interrelationship between scientific and economic globalization. The development of the global trade network not only affects the development of the global research network but is also influenced by it (Cassi, Morrison & Ter Wal, 2012). The relationship between the two is so close that some previous studies (Cassi, Morrison & Rabellotti, 2015; Parreira et al., 2017) stated that countries in a trade block are also in a research block. Joining economic agreements facilitates not only trade relations between countries but also the exchange and mobility of researchers by reducing transportation costs (ibid). Generally, research collaboration is more likely to occur between countries with large trade volumes (Hou, Pan & Zhu, 2021) or countries with more trade relations (Jeck & Baláž, 2020). Bai and Liu (2016) argued that there is a close relationship between export trade value and innovative cooperation. Therefore, considering the interaction effects of scientific and economic globalization, it seems that the development of export as one of the forms of economic cooperation has a vital role in the development of IRCs.

Social Subsystem

The first social factor is social similarity. In this study, we consider social similarity as the degree of overlap of partners (Gui, Liu & Du, 2018; 2019). Because social similarity in this sense plays a vital role in the globalization of science (Gui et al., 2018, 2019) and is one of the main determinants of the evolution of collaborative networks (Gui et al., 2018), this fact is in line with the theory of similarity-attraction. According to this theory, those with similar characteristics are more attracted to each other (Byrne, 1969). This theory is equivalent to the homophily principle in network theory. Homophily is not just about characteristics. It can also be caused by similarity in the structure of the actors' network (McPherson, Smith-Lovin & Cook, 2001). In other words, homophily creates direct links between actors with similar role relationships with similar others (Burt, 1982). Such actors are structurally equivalent (McPherson et al., 2001). Today, some network models also assume that forming links between nodes with high social similarity (structural equivalence) is more likely (Zhao et al., 2015; Zhu, Xia & Zhang, 2016). Thus, the similar characteristics and structure of the two actors' networks can attract them to each other. Applying the theory of similarity-attraction at the macro level of science indicates the tendency for scientific interaction between countries with more common partners. Social similarity has a positive and significant effect on IRCs (Plotnikova & Rake, 2014; Gui et al., 2018, 2019; Gu and Liu, 2020), and its effect has increased over time (Gui et al., 2018). Initially, the more partners two countries have, the more likely it is to have joint partners and, consequently, the more likely it is to form a cooperative tie between them.

The second social factor is international student exchange. Mearsheimer - as one of the theorists of international relations - believed that with the emergence of China as a regional hegemon in the Eastern Hemisphere and the continued position of the United States as a regional hegemon in the Western Hemisphere, it seems complicated to imagine a global hegemony (Lind, 2018). The great powers know that to secure themselves, they must reduce any possibility of a challenge to another power (Mearsheimer, 2003). For example, China's

regional hegemony is based entirely on soft power (Zhao, 2017). China has pursued educational diplomacy as part of its good neighbor strategy in foreign policy (ibid). When international students acquire knowledge of China, China's political and cultural values and themes, such as 'knowing China, being friendly with China, and loving China,' are transmitted through soft power (Wen, 2018). Generally, differences in the education system, culture, and language increase the social distance between immigrants and the host society (Ebner & Helbling, 2016). Usually, high social distance is associated with mistrust, and low social distance is associated with closeness and integration (Ebner & Helbling, 2016). International students as knowledge carriers or agents increase the likelihood of establishing or continuity of ties of research collaboration by decreasing the social distance (Choi, 2012; Kato & Ando, 2017; Gui et al., 2019; Jeck & Baláž, 2020). Hou, Fan, Du, Gui and Duan (2022) found that the countries' position in the international student mobility network has a positive and significant relationship with their position in the IRC network. Therefore, international students are not only one of the instruments of achieving the position of a regional hegemon but also lead to a superior position in the IRC network.

Cultural Subsystem

The first cultural factor is the English language. Hegemony means the domination of one group over other groups (Rosamond, 2020), and hegemony of the English language means the domination of the English-speaking population over the population of other languages. According to Gramsci, a leading scholar of cultural hegemony, language hegemony means that nations voluntarily adopt a language or that language diffusion results from power imbalances (Ives, 2009). English became a hegemonic language for reasons including the expansion of British influence by navigation in the 18th and 19th centuries, activities of missionaries of the British and later American churches to spread Protestantism, the victory of the USA and the UK - as English-spea
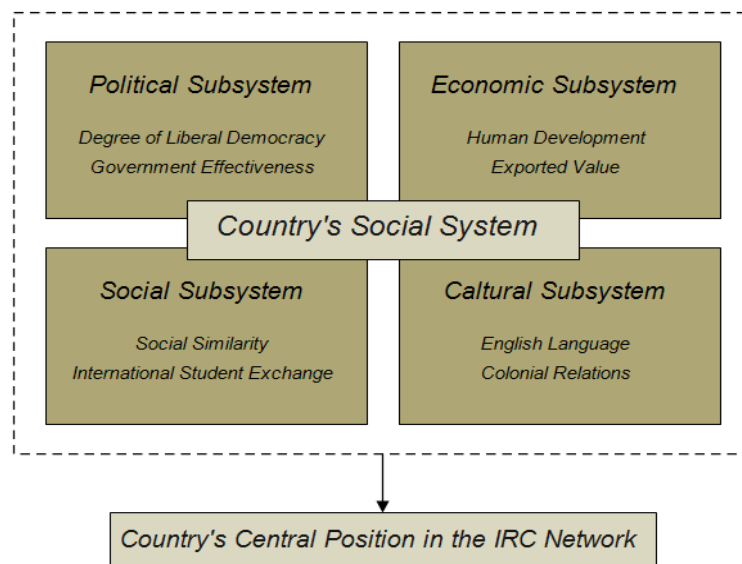

Figure 1: Theoretical Model

king countries - in World War II (Kaplan, 1993). Although English is the dominant and common language of the scientific community, its use has been problematic (Tardy, 2004). Instead of giving equal access to all countries, this language has given some countries a

privileged position, which has led them to take advantage of their preferred position in the scientific community (Tardy, 2004). For example, Gui et al. (2019) found that English-speaking countries are more likely to have research collaborations with each other. Swales (1997) also believes that English has a dual role in science: On the one hand, it is a common language for storing and retrieving information, which leads to the advancement of knowledge, and on the other hand, it is *'a powerful carnivore gobbling up the other denizens of the academic linguistic grazing grounds'* (Swales, 1997, p. 374). The dual role of the English language has led countries like the United States to become the gatekeepers of article publication (Canagarajah, 2002). As a result, part of their superior position in the IRC network is the product of this factor.

The second cultural factor is colonial relations. This cultural factor is closely related to the history of former colonial powers and colonies (Plotnikova & Rake, 2014). Today, the research collaboration between the North and the South has continued in the form of neo-colonial relations (Boshoff, 2009). Gui et al. (2019) also found that past colonial links positively and significantly affect current research collaborations. Neo-colonial relations mean indirect control of the South by the North (Jentsch & Pilley, 2003). Neo-colonialism is described as the last stage of imperialism (Nkrumah, 1974) and the resulting development is dependent (Cardoso & Faletto, 1979). Countries explained by this development are increasingly dependent on research collaboration with a scientific power at the core to improve their position in the network (Boshoff, 2009). In such a case, the central countries influence the peripheral countries' choice of topics and research methods (Schott, 1991, p. 448). Although knowledge of the core and periphery increases due to joint activity, the peripheral country succeeds only because of a partnership with a scientific power in the core (Boshoff, 2009). At present, the ability of the central countries to access, attract, and employ partners from the peripheral countries has increased (Leydesdorff & Wagner, 2008), which allows them to maintain and strengthen their position in the IRC network more and more.

The theoretical model of this study is presented in Figure 1. According to this model, we developed the following hypothesis and tried to test it using fsQCA. In Figure 1, separate arrows from the conditions/subsystems to the outcome are not drawn. Because, in fsQCA, it is assumed that all conditions/subsystems simultaneously (not independently) lead to a specific outcome (Fiss, 2007).

Hypothesis: A high degree of liberal democracy, high government effectiveness and human development, high exported value, high social similarity, high international student exchange, high English-language population, and high colonial links led to the country's central position in the IRC network.

Materials and Method

Data

This study was done using several datasets. The inter-country co-authored relations data were initially collected from the Web of Science Core Collection Database.[1] Although co-authorship is a partial indicator of research collaboration (Choi, 2012), they have a positive correlation (Glänzel & Schubert, 2005). Furthermore, most previous studies consider the co-authorship network a proxy of the research collaboration network (Choi, 2012). The Web of Science (WOS) Database was selected because it is one of the largest and most comprehensive databases for collecting IRC data (Gui et al., 2019). The data retrieved from the WOS Database included the number of articles co-authored between each pair of countries in all disciplines

and all languages. In the present study, we refer to the country as an independent territory recognized by the United Nations. The lack of data for non-independent territories in some conditions led to their exclusion from the study.[2] The list of independent countries and the date of independence was extracted from the Online Browsing Platform (OBP)-ISO 3166. We collected the data from the beginning of the 21st century because it was during this period that some semi-peripheral countries could achieve a central position (Gui et al., 2019). However, due to the lack of data in some conditions for 2000-2001 and 2018-2022, the period was inevitably limited to 2002-2017. There were 2,644 country-year observations (On average, 165 countries each year). Table 1 summarizes the measures and data sources.

Table 1

Summary of measures and data sources

Measure	Notation	Description	Source(s)
Outcome			
Central position in the co-authorship network	Net_Pos	The weighted degree centrality scores in the IRC network, as calculated by Eq. (1).	Web of Science.
Political Conditions			
(1) Degree of liberal democracy	Lib_Dem	The extent to which the idea of liberal democracy is realized ranges from 0 to 1.	V-Dem Dataset (v.12).
(2) Government effectiveness	Gov_Eff	The indicator of government effectiveness.	The Worldwide Governance Indicators (WGI) project.
Economic Conditions			
(3) Human development index	HDI	The three indicators of measuring human development include life expectancy, education, and GNI.	UN Database.
(4) Exported value	Exp_Val	The exported value (in US dollars) by country and year.	The International Trade Centre (ITC) database.
Social Conditions			
(5) Social similarity	Soc_Sim	The median of the Jaccard similarity (Eq. 2) of each country to its collaborators.	/
(6) Position in the international student mobility network	Int_Stu	The weighted degree centrality scores (based on the summation of in-degree and out-degree) in the international student mobility network.	UNESCO Database.
Cultural Conditions			
(7) English-language population (%)	Eng_Lan	The percentage of the English-language population by country.	UN Demographic Statistics Database; The CIA World Fact Book.
(8) Degree of scientific dominance	Deg_SciDom	The ratio of the former colonizer's research collaborations with its former colonies, as calculated by Eq. (3).	Authoritarian Regimes Dataset (v.6); Bjørnskov-Rode Regime Dataset (v.3.2).

The following data were also collected for each country-year observation: (1) degree of liberal democracy; (2) government effectiveness; (3) human development index; (4) exported value; (5) in-flow and out-flow of international students; (6) number of English-language population; (7) colonial records.

Measures

Outcome: Central Position in the Co-authorship Network

To determine the countries' position in the IRC network, in the first step, we calculated the

countries' strength scores (or weighted degree centrality scores) in the IRC network (Borgatti and Everett, 2000; Chang et al., 2017,[3] Falzon, Quintane, Dunn & Robins, 2018). The strength scores denote the sum of co-publications of each country with its partners (Barrat, Barthelemy, Pastor-Satorras & Vespignani, 2004), and are calculated as follows:

$$S_i = \sum_{j=1}^{n} WE_{ij} \qquad\qquad (1)$$

Where WE_{ij} is the weight of the edge of vertex *i* with each adjacent vertex (*j*). In other words, it is the number of co-publications of country *i* with country *j*. The strength scores were calculated using the R package *igraph*. When countries are sorted based on strength scores, countries with higher scores are in the central position, and countries with lower scores are in the peripheral position. Also, countries with medium scores are in the semi-peripheral position.

In the second step, following Chang et al. (2017), we used the K-means clustering method to separate the boundaries of positions from each other. K-means cluster data points into unique, non-overlapping subgroups (clusters) where each data point belongs to **only one group**. It tries to make the intra-cluster data points as similar as possible while also keeping the clusters as different (far) as possible. It assigns data points to a cluster such that the sum of the squared distance between the data points and the cluster's centroid (arithmetic mean of all the data points that belong to that cluster) is at the minimum. The less variation we have within clusters, the more homogeneous (similar) the data points are within the same cluster (Hill, Lewicki & Lewicki, 2006). In this method, the number of clusters is determined by the researcher. Here the number is four. Because there are four positions. Hence, each cluster represents a position. In general, the use of this method shows which countries are classified under each position.

We classified countries based on strength scores into four clusters (*k* = 4). The clustering was repeated separately for the existing countries each year (from 2002 to 2017). In each year, the first cluster contains countries with high degrees of research collaboration (i. e., countries with a central position), and the second and third clusters contain countries with medium degrees of research collaboration (i. e., countries with semi-peripheral position). The fourth cluster contains countries with low degrees of research collaboration (i. e., countries with peripheral positions). Thus, as the countries' degree of research collaboration decreases, their position in the network also degrades. We assigned two clusters to the semi-peripheral position to use the boundary of the second and third clusters as a crossover point in the data calibration step. Gui et al. (2019) believe such a distinction exists within the semi-peripheral position. That is why they refer to the second and third clusters as *'strong semi-peripheral position'* and *'semi-peripheral position'*, respectively. The latter position is also called *'weak semi-peripheral'* (Ruvalcaba, 2020).

When data are clustered with the K-means, a few countries with the highest strength scores form separate clusters. This is because the K-means cluster is sensitive to outliers (Sammut & Webb, 2011; Kaushik & Mathur, 2014). So in the third step, since the strength scores of outliers were in the 99th percentile, we left them out (Gold, 2020; Sastry, 2020; Cohen et al., 2022). We then reclassified the rest of the countries into four clusters. Finally, we added the outliers to the first cluster (i. e., the cluster of central countries).

Conditions

Degree of liberal democracy: argued that the liberal principle of democracy emphasizes the importance of protecting individual and minority rights against the tyranny of the state and the tyranny of the majority (For details see Coppedge et al., 2022). To measure the extent to which the idea of liberal democracy has been realized in each country, we used the Liberal Democracy Index in the V-Dem Dataset (v.12). The values of this index are between 0 and 1. The values close to 1 indicate the higher degrees of liberal democracy, and the values close to 0 indicate the lower degrees of liberal democracy.

Government Effectiveness: To examine government effectiveness, the indicator of government effectiveness in the Worldwide Governance Indicators (WGI) project was used. These indicators measure six broad dimensions of governance: Voice and Accountability, Political Stability and Absence of Violence/Terrorism, Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption. In this project, government effectiveness means perceptions of the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government's commitment to such policies (Kauffmann, Kraay & Mastruzzi, 2010).

Human development index: This is a composite index measuring average achievement in basic dimensions of human development-a long and healthy life (life expectancy index), knowledge (education index), and a decent standard of living (GNI index)[4.] The data on HDI were collected from the United Nations database.

Exported value: For international export, we got the list of exporters for all products (based on the exported value in US dollars) from the International Trade Centre (ITC) database.

Social similarity: This indicator measures the degree of overlap of partners for each pair of countries (Granovetter, 1973). In other words, to what extent do two countries collaborate with collaborators of each other? One way to calculate this indicator is to use the Jaccard similarity coefficient. Huynh, Hoang and Lam (2013, p. 13) defined the Jaccard similarity coefficient as follows: *'Jaccard similarity coefficient of two vertices is the number of common neighbours divided by the number of vertices that are neighbours of at least one of the two vertices being considered'*. So:

$$Sim_{Jaccard}(X,Y) = \frac{|n_X \cap n_Y|}{|n_X \cup n_Y|} \tag{2}$$

Where n_X is the set of neighbours of vertex X, $|n_X \cap n_Y|$ is the number of common sharing neighbors of X and Y, $|n_X \cup n_Y|$ is the number of neighbors of X and Y, and $|n_X|$ is the number of neighbors of vertex X (Huynh et al., 2013, p. 14). The values of this coefficient range from 0 to 1. Values close to one mean that two vertices are more similar, and values close to zero mean that two vertices are less similar. In this study, the R package *igraph* was used for calculating the values of the Jaccard similarity coefficient. Since this coefficient is calculated for each pair of vertices, the resulting values are represented as a square similarity matrix. To convert the similarity matrix to a variable, the median of the Jaccard similarity values of each country to its collaborators was calculated. The median was used because there were outliers in the ego network of some countries. In this way, there is only one social similarity value for each country.

Position in the international student mobility network: International students have crossed a national or territorial border for education and are now enrolled outside their country of

origin[5]. To determine the countries' position in the international student mobility network, the same three-step process that was mentioned in the outcome was followed: (1) calculation of strength scores; (2) identifying outliers; (3) clustering the countries based on strength scores using the k-means method. The difference is that in the first step, the strength scores were calculated based on both the in-flow and out-flow international students. Because, unlike the IRC network, the international student mobility network is a directed one. The strength score in such a network is the sum of the weight of arcs of each vertex with adjacent vertices (i. e., the total number of students entering or leaving each country to educate). The strength scores were calculated using the R package *igraph*. After identifying the outliers, the countries (available each year) were classified into four clusters, and the outliers were added to the first cluster. The first cluster belonged to the central position, the second and third clusters to the semi-peripheral position, and the fourth cluster to the peripheral position. We used the UNESCO database for international student data. The selected dataset was the total number of inbound internationally mobile students, both sexes, by country of origin and year[6.]

Percent of English-language population: For this indicator, the total number of the English-speaking population of the countries is converted into a percentage so that all values are on a single scale. Because changing the English-speaking population takes a long time (50-100 years) and their numbers are relatively stable (Graddol, 1998), the percentage of the English-speaking population for each country is kept fixed from 2002 to 2017. Data on the English-speaking population by country were collected from two sources (see Table 1).

Degree of scientific dominance: According to Gui et al. (2019), some former colonies (such as Algeria, Morocco, and Tunisia) maintained strong ties of scientific collaboration with their former colonizer (such as France). Therefore, the continuation of this collaboration is examined in the form of an indicator. It is the ratio of the former colonial power's research collaborations with its former colonies. This indicator shows what proportion of former colonial power's research collaborations are products of former colonial relations. An indicator called the 'degree of scientific dominance' was defined to measure the above. This indicator measures what percentage of the total research collaborations of colonizer i is with its former colonies j; i. e.:

$$DSD_i = \frac{\sum_{k=1}^{n} WE_{ik}}{S_i} . 100 \tag{3}$$

Where WE_{ik} is the total number of research collaborations of vertex i (colonizer) with vertices k (former colonies of vertex i). This indicator was calculated for all countries. It only had values greater than zero for the colonial powers that continued to collaborate with their former colonies. It was zero for the colonial powers that did not collaborate with their former colonies and countries that were not colonizers. Higher values mean higher degrees of scientific domination of the colonial power over its former colonies. In contrast, smaller values mean a reduction in the scientific domination of the colonial power over its former colonies. In summary, this indicator shows which colonizers are still the main collaborators of their former colonies and have a particular position in the network of their colonies. The names of colonial powers and their colonies were collected from two Datasets (see Table 1).

Data Analysis Procedure
Stage 1: Position Analysis
The countries' weighted degree centrality scores were clustered to identify the countries'

position in the IRC network. No country can occupy more than one position simultaneously. Thus, each country-year observation can solely fall in one of these four positions: central, strong semi-peripheral, weak semi-peripheral, or peripheral. After determining the countries' position each year, all country-year observations were entered into the stage of fsQCA. However, only the factors influencing the central position in the IRC network were identified (i. e., the factors influencing high scores of weighted degree centrality).

Stage 2: Fuzzy-set Qualitative Comparative Analysis (FsQCA)

Two well-known approaches in comparative studies are crisp sets and fuzzy sets. The fuzzy sets approach was developed to overcome the limitations of the approach of the crisp set (Ragin, 2005). While the approach of the crisp set considers the membership of cases in a set as zero (non-membership in the set) or one (membership in the set), the fuzzy sets approach considers the degree of membership of cases in a set. Degrees of membership are scores ranging from zero (full non-membership in the set) to one (full membership in the set) (Rihoux & Ragin, 2009). Attributing tags such as "fully in", "more in than out", "more out than in", and "fully out" to the degrees of membership of the cases in each set has led to the fuzzy sets approach is both a quantitative and a qualitative one (Ragin, 2000). A comprehensive reference to the above two approaches, and other approaches available in the comparative studies, is Rihoux and Ragin's (2009) book *Configurational Comparative Methods: Qualitative Comparative Analysis (QCA) And Related Techniques*. Generally, fsQCA primarily requires knowing the degree of membership of cases in several variables. The variables are condition(s) and outcome. Condition(s) are considered as independent variable(s) and outcome as dependent variable. This method tries to identify the causal combinations affecting the outcome. In other words, the fsQCA answers the question of the presence or absence of which conditions lead to the occurrence of the outcome.

This study is based on two strategies suggested by Verweij and Vis (2021) for tracking configurations over time with fsQCA: (1) *strategy of fuzzy-set ideal type analysis*; (2) *strategy of multiple periods, single fsQCA*. Although there are many quantitative (e. g., time series analysis, survival analysis, and event history modeling) and qualitative (e. g., process tracing and sequence analysis) approaches that focus on the issue of time, none are suitable for *tracking configurations over time* (Verweij & Vis, 2021).

The fsQCA works with data ranging from 0 to 1. To place the data in this range, it is necessary to calibrate them based on three points: full membership, full non-membership, and a crossover. Following de Block and Vis (2017), Duşa (2019), Beynon, Jones & Pickernell (2020), and ben Jabeur, Mefteh-Wali, Carmona (2021), data were calibrated using a K-means cluster approach. It is suggested to calibrate the data based on the researcher's substantive knowledge of the cases (Ault &Spicer, 2020). Since the researcher is unlikely to have sufficient knowledge about all the cases, this calibration approach is not practical for large-N fsQCAs (Greckhamer, Misangyi & Fiss, 2013). That is why it is recommended to use methods such as clustering for calibration. In this approach, there is a significant difference between the mean values of clusters (Hill et al., 2006). Hence, it is an excellent way to calibrate interval/ratio variables. The calibration thresholds for conditions/outcomes are presented in the Appendix (Table 5: calibration column).

After data calibration, an analysis of the necessary conditions was performed. The necessity analysis in fsQCA is a separate procedure that examines whether individual conditions are

necessary for the outcome (Beynon et al., 2020). Regarding the set theory, when Y is a subset of X, we can say that X is a necessary condition for Y (Goertz, 2006). In other words, a necessity relation is observed in fuzzy sets when fuzzy scores of X are greater than the fuzzy scores of Y (Duşa, 2019). In this analysis, two crucial indicators are *consistency* and *coverage*, ranging from 0 to 1. Ragin (2006, p. 292) defined them as follows: *'Consistency assesses the degree to which the cases sharing a given condition or combination of conditions agree in displaying the outcome in question, and coverage assesses the degree to which a cause or causal combination 'accounts for' instances of an outcome'.* To analyze necessary conditions, the Relevance of Necessity (RON) indicator should also be evaluated. The values of this indicator are between 0 and 1.
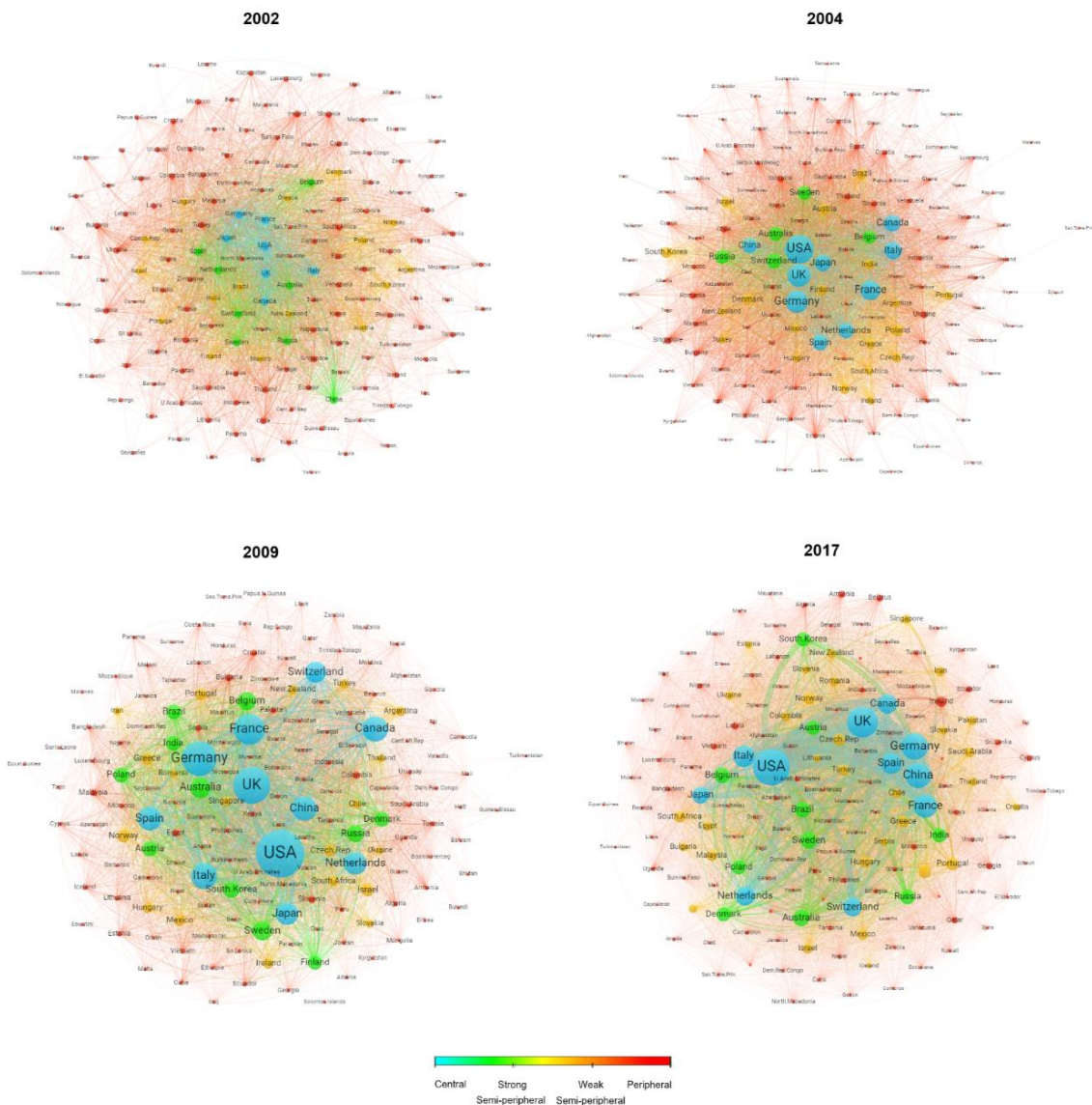

Figure 2: Dynamics of the IRC network in the period 2002-2017

The greater the RON value of a condition, the greater the importance as a necessary condition (Duşa, 2019). Using a consistency threshold of 0.90, a coverage threshold of 0.60, and a RON threshold of 0.60 (Thomann, van Engen & Tummers, 2018), it was evaluated whether each condition was necessary for the outcome.

A truth table was generated to implement the fuzzy-set ideal-type analysis strategy. This strategy focuses on tracking *cases* over time (cases-as-configurations) (Verweij & Vis, 2021).

The results indicate when a social system faces qualitative or quantitative change (a descriptive approach) (Verweij & Vis, 2021). The qualitative change indicates the movement of the social system from one ideal type to another (Verweij &Vis, 2021). Byrne (2005; 2009) considered such a change a *'phase shift'* in the social system. In contrast, quantitative change indicates an increase/decrease in the degree of membership of a social system in a fixed ideal type (Verweij & Vis, 2021). With eight conditions, the truth table has $2^8 = 256$ rows (or the ideal types). Each ideal type is a combination of conditions. The outcome is not considered here. A case (i. e., a country-year observation) belongs to an ideal type if it has a membership score of more than 0.5 (Verweij & Vis, 2021). Each case can belong to one ideal type at the same time.

The truth table was minimized to implement the strategy of multiple periods, single fsQCA. This strategy focuses on tracking solution *terms* (i. e., configurations) over time (Verweij & Vis, 2021). The results indicate how cases move between configurations over time or, conversely, how configurations are represented by cases over time (an explanatory approach) (Verweij & Vis, 2021). In other words, it examines the sufficient conditions for the central position in the IRC network. For minimizing the truth table, a consistency threshold of 0.911 (Verweij & Vis, 2021), a PRI threshold of 0.5, and a frequency threshold of 3 (Pappas & Woodside, 2021) were selected. An intermediate solution minimizes the truth table. Because this solution is not too complex (Cervelló-Royo, Moya-Clemente, Perelló-Marín & Ribes-Giner, 2020), it is easy to interpret (Mendel & Korjani, 2012) and is the most helpful solution (Mendel, 2013). Following Ragin (2009), a model with a solution consistency (Solution InclS) of above 0.74 and solution coverage (Solution CovS) between 0.25 and 0.65 was considered an informative model. Finally, the validity of the results is checked using a robustness analysis.

Results

Position Analysis

The results of determining the countries' position in the IRC network from 2002 to 2017 are presented in Figure 2. In this figure, the graphs related to the beginning (2002) and end (2017) of the period are displayed, as well as the graphs related to the times when new countries were added to the central position (i. e., the graphs 2004 and 2009). Therefore, the central countries are categorized into two groups: (1) countries that have maintained their central position throughout the period 2002-2017 include the USA, Canada, Japan, and the Big Four of Europe, also known as G4 countries (i. e., the UK, Germany, France, and Italy); (2) countries upgraded from a strong semi-peripheral position to a central position and have maintained the new position include China, Netherlands, Spain (from 2004), and Switzerland (from 2009).

Analysis of Necessary Conditions

According to Table 2, no single condition is necessary for the central position. Thus, this study looked for potential configurations of these causal conditions that lead to the central position in the IRC network.

Table 2
Necessary conditions for the central position in the IRC network (2002-2017)

Conditions	Consistency	RON	Coverage	Conditions	Consistency	RON	Coverage
High Lib_Dem	0.89	0.67	0.30	~High Lib_Dem	0.27	0.43	0.07
High Gov_Eff	0.89	0.68	0.31	~High Gov_Eff	0.31	0.42	0.07
High HDI	0.96	0.54	0.25	~High HDI	0.21	0.55	0.06
High Exp_Val	0.53	0.99	0.90	~High Exp_Val	0.68	0.09	0.11
High Soc_Sim	0.80	0.51	0.21	~High Soc_Sim	0.39	0.58	0.12
High Int_Stu	0.69	0.96	0.73	~High Int_Stu	0.55	0.15	0.09
High Eng_Lan	0.31	0.87	0.26	~High Eng_Lan	0.83	0.19	0.14
High Deg_SciDom	0.30	0.98	0.67	~High Deg_SciDom	0.87	0.07	0.13

Analysis of Sufficient Conditions
The Strategy of Fuzzy-set Ideal Type Analysis: Typology of the Central Countries

Figure 3 shows the ideal types in the central countries from 2002 to 2017. While Table 3 shows the ideals types that occurred in the countries' centrality period. In other words, the ideal types belonging to China (2002-2003), Netherlands (2002-2003), Spain (2002-2003), and Switzerland (2002-2008) were removed from Table 3. Because these countries were in a strong semi-peripheral position in the mentioned periods (Figure 2). According to Table 3, 20 configurations lead to the central position and correspond to these configurations, there are also 20 types of central countries.

In Figure 3, each combination of conditions is represented by one color. Color change means a qualitative change (phase shift) in the social system. A quantitative change occurs in the social system when its degree of membership in a combination varies, while its color remains unchanged. Here, we use a symbolic letter for each condition to make it easier to name the phase shifts. The symbolic letters are high Liberal democracy (L), high Government effectiveness (G), high HDI (H), high Exported value (X), high social similarity (S), high international student (I), high English language (E), high degree of scientific dominance (D). Figure 3 helps to identify the minimum necessary conditions for improving the level of scientific collaboration in liberal democratic and non-liberal democratic systems.

According to Figure 3, the improvement of the network position coincides with a phase shift. There are three examples of this fact. First, the change of China's position from a strong semi-periphery to a central one in 2004 was parallel to the change of the country's economic subsystem from an economic system without high exported value to an economic system with high exported value; Second, the improvement of Spain's position in 2004 was parallel to the improvement of the social subsystem of this country (both in terms of strengthening interactions with collaborators of collaborators and in terms of international student exchanges); Third, the improvement of the position
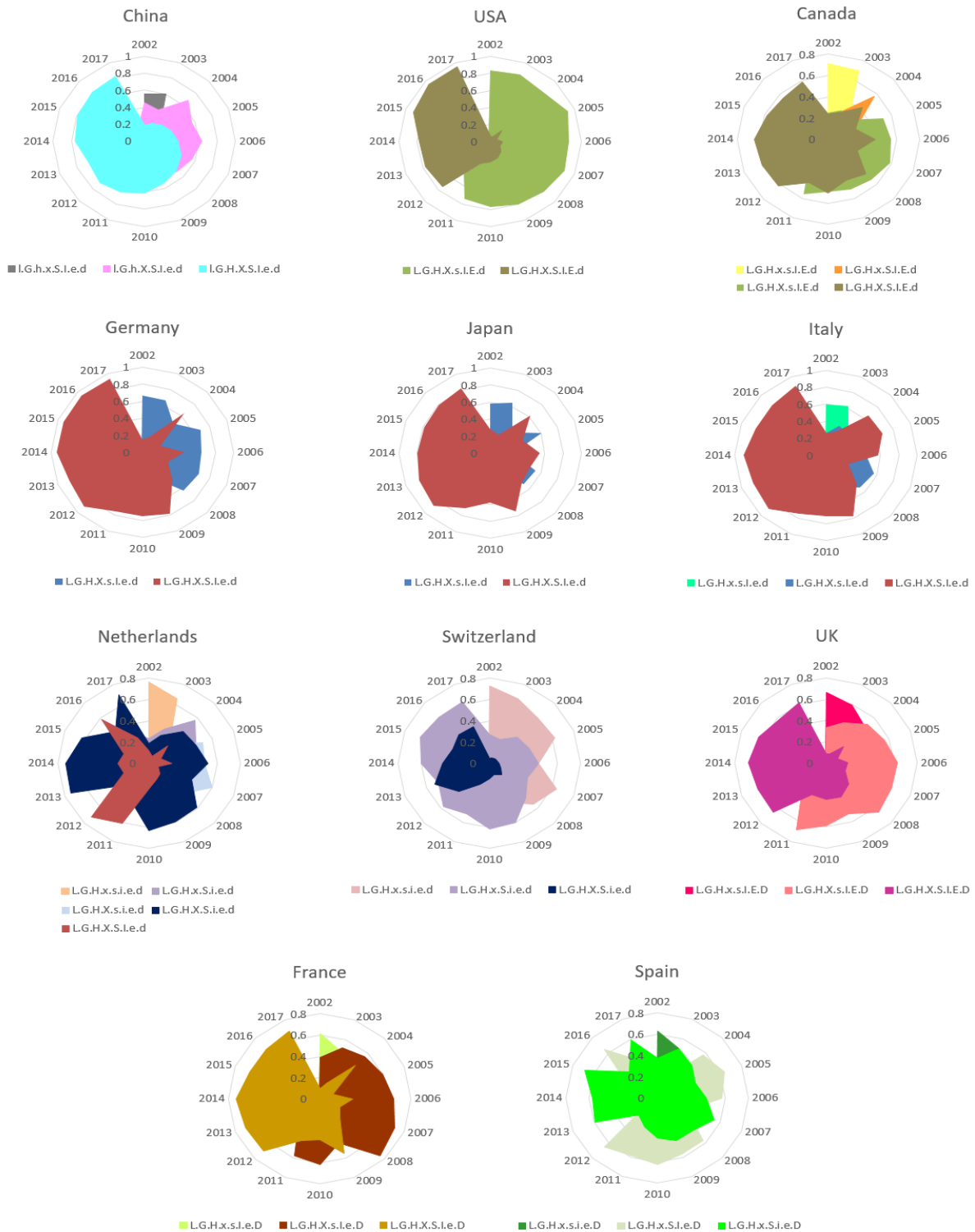
Figure 3: The qualitative and quantitative changes in the central countries' social system. A capital letter symbolizes the presence of the condition, and a lowercase letter symbolizes the absence of the condition. The dot (.) means "and". The abbreviated symbol for each condition is as follows: high/~high Liberal democracy (L/l), high/~high Government Effectiveness (G/g), high/~high HDI (H/h), high/~high Exported value (X/x), high/~high social similarity (S/s), high/~high international student (I/i), high/~high English language (E/e), high/~high Degree of scientific dominance (D/d).

of the Netherlands and Switzerland in 2004 and 2009, respectively, was parallel to the improvement of one of the elements of the social subsystem (i. e., strengthening interactions with collaborators of collaborators).

According to Table 3, some countries had similar phase shifts during their centrality period. For example, Germany, Italy, and Japan changed from a system without high social similarity to one with high social similarity (Types 13 and 17, respectively). This shift for Germany and Japan occurred in almost the same period. The USA and Canada also had a similar phase shift. Both countries changed from a system without high social similarity to one with high social similarity (Types 15 and 19, respectively). However, other phase shifts have occurred in Canada before 2005 (Types 6 and 9) that have not occurred in the USA. In other words, all the above countries have shifted towards strengthening interactions with common partners (or collaborators of collaborators).

All central countries have a liberal democratic political system except China (Table 3: column 1). In addition, the only common condition among all central countries of the network is high government efficiency (Table 3: column 2). According to Table 3, the states of occurrence of the central position in the presence of minimal conditions/subsystems are:

Type 1: A non-democratic system with high government effectiveness, high exported value, high social similarity, and high international student (4 conditions/3 subsystems).

Type 2: A democratic system with high government effectiveness, high exported value, and high social similarity (4 conditions/3 subsystems).

Type 4: A democratic system with high government effectiveness, high HDI, and high international student (4 conditions/3 subsystems).

Type 11: A democratic system with high government effectiveness, high HDI, and high exported value (4 conditions/2 subsystems).

Thus, at least four conditions from 2-3 subsystems must be present to place a system in the central position. Types 2, 4, and 11 are attributed to liberal democracy systems, and Type 1 is attributed to non-liberal democracy systems. Changes in economic or social conditions always cause qualitative shifts. While political or cultural conditions are always constant (Table 3). In addition, cultural conditions lead to a central position only if conditions from all three other subsystems are present. For example, Spain (2002-2003) was not placed in the central position despite having two political conditions, one economic condition, and one cultural condition. In contrast, France (2002) was placed in the central position due to having an additional social condition compared to Spain (Figure 3).

The Strategy of Multiple Time Periods, Single FsQCA: Causal Configurations Leading to the Central Position

The results of minimization are presented in Table 4. The model presented in Table 4 is informative for the central position because it has excellent consistency (0.917) and suitable coverage (0.592). According to the causal configurations obtained in Table 4, the hypothesis of this study is rejected. Because none of the causal configurations have all eight conditions. However, Table 3 shows that the UK has had all eight conditions simultaneously from 2012 to 2017. Since the UK is in common with France (2009; 2012-2017), and Spain (2004-2006; 2008-2012; 2016) in the causal configuration 4 (see Table 4) and France has no high *Eng_Lan* and Spain has no high *Eng_Lan* and high *Exp_Val*, the last two conditions have been removed in the minimization process.

In addition, the results of Table 4 contain several points. First, in a general classification, it can be observed that the causal configurations leading to the central position are divided into two categories: (1) causal configurations based on non-cultural conditions (Solution Terms 1 and 2); (2) causal configurations based on the presence of a cultural condition include the configuration related to English-speaking countries (Solution Term 3) and the configuration related to the former colonial powers (Solution Term 4). The first causal configuration is based solely on political and economic conditions. In the second causal configuration, social conditions are also present. Only the third and fourth causal configurations have conditions from all four subsystems. However, government effectiveness is a common condition among all four causal configurations.

Second, most cases are covered with causal configuration 1. This configuration includes both conditions of the political subsystem as well as both conditions of the economic subsystem. Germany and Japan have continuously followed this causal configuration throughout the period 2002-2017. Italy and the Netherlands are also explained mainly by the same configuration. This configuration temporarily explains some countries. For example, France is explained with this configuration before 2011. France, after developing its network around the collaborators of collaborators, is explained mainly by configuration 4. Also, Switzerland was explained by configuration 1 in 2013 because it achieved a high level of exported value only this year.

Third, the causal configuration of some central countries has changed similarly. For example, the USA and Canada have shifted from configuration 3 before 2011 to configuration 2 mainly after 2012 due to increasing social similarity.

Fourth, all the central countries whose causal configurations changed during 2002-2017 (including the US, Canada, the UK, and France) have remained continuously on their new causal configuration since 2012. The change of causal configuration in all the above cases has occurred due to the increase in social similarity (except for Canada2002-2003, due to the increase in the level of exported value).

Table 3
Typology of the central countries in the IRC network

Type	Lib_ Dem	Gov_ Eff	HDI	Exp_ Val	Soc_ Sim	Int_ Stu	Eng_ Lan	Sci_ Dom	Case(s)
1	~High	High	~High	High	High	High	~High	~High	China (2004-2008).
2	High	High	High	~High	High	~High	~High	~High	Netherlands (2004), Switzerland (2009-2012; 2014-2017).
3	High	High	High	~High	High	~High	~High	High	Spain (2007; 2013-2015; 2017).
4	High	High	High	~High	~High	High	~High	~High	Italy (2002-2003).
5	High	High	High	~High	~High	High	~High	High	France (2002).
6	High	High	High	~High	~High	High	High	~High	Canada (2002-2003).
7	High	High	High	~High	~High	High	High	High	UK (2002-2003).
8	High	High	High	~High	High	High	~High	High	Spain (2004-2006; 2008-2012; 2016).
9	High	High	High	~High	High	High	High	~High	Canada (2004).
10	~High	High	High	High	High	High	~High	~High	China (2009-2017).
11	High	High	High	High	~High	~High	~High	~High	Netherlands (2005; 2007).
12	High	High	High	High	High	~High	~High	~High	Netherlands (2006; 2008-2010; 2013-2015; 2017),

Type	Lib_ Dem	Gov_ Eff	HDI	Exp_ Val	Soc_ Sim	Int_ Stu	Eng_ Lan	Sci_ Dom	Case(s)
									Switzerland (2013).
13	High	High	High	High	~High	High	~High	~High	Germany (2002-2003; 2005-2008), Italy (2007-2008), Japan (2002-2003; 2005; 2007-2008).
14	High	High	High	High	~High	High	~High	High	France (2003-2008; 2010-2011).
15	High	High	High	High	~High	High	High	~High	Canada (2005-2009; 2011), USA (2002-2011).
16	High	High	High	High	~High	High	High	High	UK (2004-2011).
17	High	High	High	High	High	High	~High	~High	Germany (2004; 2009-2017), Italy (2004-2006; 2009-2017), Japan (2004; 2006; 2009-2017), Netherlands (2011-2012; 2016).
18	High	High	High	High	High	High	~High	High	France (2009; 2012-2017).
19	High	High	High	High	High	High	High	~High	Canada (2010; 2012-2017), USA (2012-2017).
20	High	High	High	High	High	High	High	High	UK (2012-2017).

The centrality period of some countries, like China, can be explained by only one causal configuration because the main conditions leading to their central position have always existed in the same fixed configuration.

The cases that are not explained, like Spain (2007; 2013-2015; 2017), are in the configurations with a consistency threshold of less than 0.911 a PRI threshold of less than 0.5, or a frequency threshold of less than 3.

Robustness Checks

We conducted a robustness analysis to check the validity of the results. Following Hofstad's (2019) method, we determined the robustness range for the calibration thresholds of each set. Within these ranges, the solution terms and the cases remain the same. Since in-depth case knowledge is not always accessible in large-*N* fsQCAs, identifying the robustness range is beneficial (Emmenegger, Schraff & Walter, 2014). The robustness ranges are presented in Appendix (Table 5: columns 3 and 4). The robustness ranges indicate that the upper bound has a higher coverage (0.606). In contrast, the lower bound has higher consistency (0.932).

In addition, we checked the stability of the solution terms and the cases against changing the consistency threshold (Cooper & Glaesser, 2016). Here, everything is fixed, and only the consistency threshold changes. This investigation showed that the same solution terms and cases are obtained up to the threshold of 0.925. The values of solution consistency and coverage are the same as before up to the above threshold.

Table 4
The causal configurations leading to the central position in the IRC network

	Solution Terms	InclS	PRI	CovS	CovU	Cases
1	*Lib_Dem*Gov_Eff *HDI*Exp_Val*	0.973	0.956	0.458	0.084	France (2003-2008; 2010-2011), Germany (2002-2017), Italy (2004-2017), Japan (2002-2017), Netherlands (2005-2017), and Switzerland (2013).
2	*Gov_Eff*Exp_Val* Soc_Sim*Int_Stu*	0.954	0.917	0.393	0.058	Canada (2010; 2012-2017), China (2004-2017), USA (2012-2017).
3	*Lib_Dem*Gov_Eff *HDI*Int_Stu* Eng_Lan*	0.935	0.887	0.246	0.048	Canada (2002-2003; 2005-2009; 2011), UK (2004-2011), USA (2002-2011).
4	*Lib_Dem*Gov_Eff *HDI*Soc_Sim* Int_Stu*Sci_Dom*	0.920	0.791	0.202	0.021	France (2009; 2012-2017), Spain (2004-2006; 2008-2012; 2016), UK (2012-2017).
	Solution	0.917	0.873	0.592		

Discussion

This study determined the causal configurations that lead to countries' central position in the IRC network from Parsons' social system perspective. Three key findings are as follows: First, based on the position analysis, the USA, UK, Germany, France, Italy, Japan, and Canada have enjoyed a stable central position in the IRC network throughout the period 2002-2017. China, Spain, the Netherlands, and Switzerland were promoted from a strong semi-peripheral position to a central position during this period. Second, using the fuzzy-set ideal type analysis, twenty configurations leading to the central position and twenty types of central countries were identified. Third, using the single fsQCA for multiple periods, four main causal configurations leading to the central position in the IRC network were identified.

Consistent with previous research (Vieira et al., 2022), this study found that government effectiveness is one of the most critical determinants of the countries' position in the IRC network. This factor is present in all causal configurations and all types of central countries. In line with the study of Gui et al. (2019), causal configuration 4 in Table 4 indicated that France, Spain, and the UK maintained collaborative ties with their former colonies more than other former colonial powers. According to the causal configurations 1, 3, and 4 in Table 4, this study confirms the role of liberal democracy in the scientific development of Western societies. The above finding is consistent with the claims of Coppedge et al. (2011).

However, the presence of China among the central countries indicates that the promotion to the central position is not necessarily dependent on the presence of liberal democracy (see the causal configuration 2 in Table 4). As Xie, Zhang and Lai (2014) stated, China's economic growth and investment in human resources have a significant impact on China's current position in the global science system. This fact means that regardless of the type of political system, a country can realize a high level of scientific development due to having a prominent position in the economic system. However, China's policy toward becoming a regional power by investing in international students and scientific networking through common partners should not be ignored.

Also, previous studies have drawn inconsistent conclusions regarding the English language factor. There is much evidence that English as an international language plays a facilitating role in research collaborations (Tardy, 2004; Gui et al., 2019; Yow & Lim, 2019). Causal configuration 3 in Table 4 showed that the English language only played a crucial role in the central position until 2011. Overall, the proposition that this research added about cultural factors (including language and colonial links) was that these factors only help a country to be in a central position when combined with political, economic, and social factors.

This study also added a new insight that somehow supports the findings of previous studies. This insight is that transitioning from a strong semi-peripheral position to a central position coincides with a phase shift in the social system. The phase shift is the product of a change in the economic or social subsystem. China is an excellent example of a phase shift due to an economic factor. Xie et al. (2014) considered human capital and a centralized government willing to invest in science as critical factors in China's continuing scientific rise. This study also confirms that China's latest phase shift occurred due to an improved human development index. In addition, the absence of liberal democracy and the high efficiency of the government has always played a role in China's central position. The social similarity is also a factor that caused the phase shift of all the western powers of the network. Ter Wal (2014) argued that the German biotechnology network was formed under the influence of the mechanism of social similarity. This research extends the findings of Ter Wal (2014) to the IRC networks of the USA, Canada, Japan, Italy, Netherlands, Switzerland, UK, France, Spain, and Germany in all disciplines.

Implications, Limitations, and Future Research Directions
Implications for Literature

The present study contributes to the relevant literature in three ways. First, this study extends the literature on IRC by investigating the factors affecting the network position. There are many studies about discovering the countries' position in the IRC network, but why some of them are in a central position has not been considered so far.

Second, by drawing upon the social system framework, this study provides an understanding of how different subsystems can contribute in different ways to maintaining or promoting a central position in the IRC network. Previous studies without relying on any theoretical approach have provided a classification of factors affecting the IRC. In contrast, this study has taken a holistic approach to classifying factors.

Third, in this study, the identification of causal configurations leading to the central position is based on tracking causal configurations over time with fsQCA. The difference between this approach and conventional regression models is in the attention to causal complexity. The regression models are based on identifying the independent effect of factors on the dependent variable. In contrast, the fsQCA is based on identifying combinations of factors that simultaneously lead to the desired outcome. By adopting the fsQCA, this study also advances the literature on the role of liberal democracy in the development of science. This study presents the causal configurations for achieving the central position for both democratic and non-democratic societies. In addition, the causal configurations for achieving the central position for liberal democratic societies with/without cultural background are also presented separately.

Implications for Practice

Since changing political and economic conditions is time-consuming and requires various resources, the following four policy suggestions are focused on social and cultural conditions. First, the formation of a research area consisting of the central and strong semi-peripheral countries to solve common problems of these countries and also improve the strong semi-peripheral countries' position. Considering that the structure of these countries' networks is highly similar, their network of research collaboration has formed a separate research block. Suppose this block officially becomes a coherent research area through an agreement. In that case, it can help to solve common problems through the mutual exchange of information in the form of holding conferences, workshops, summer schools, and so on. In addition, the transfer of knowledge from central countries to strong semi-peripheral countries helps improve human development in strong semi-peripheral countries.

Second, strengthen national policies to allocate the necessary funds to universities to attract international students and, in return, encourage domestic students to study abroad along with guarantees for their return. Physical proximity is no longer a requirement for scientific collaboration (Gui et al., 2018, 2019). However, in some disciplines, geographical distance is still an obstacle to collaboration (Parreira et al., 2017; Avdeev, 2021). Hence, the guarantees for the return of students seem necessary. This policy should be followed more seriously in countries with a strong semi-peripheral position in the IRC network and a weak semi-peripheral position in the international student mobility network (such as Austria, Belgium, Brazil, Czech Republic, Denmark, Greece, Poland, Portugal, Russia, and Sweden) or even with a peripheral position in the international student mobility network (such as Finland and Norway).

Third, pursuing the policy of nationalizing English as a second language. This policy is more practical, especially in countries where knowledge of the English language is expanding. At the same time, the results indicated that the English language played a vital role in the central position until 2011. Thus, pursuing policies aimed at the full spread of the English language in a nation is not very cost-effective today.

Fourth, concluding research cooperation agreements between countries with a strong semi-peripheral position with regional leaders to reduce scientific dependence on former colonial powers. Although strengthening the scientific collaboration between the former colonizer and the former colony is in the interest of the colonizer, it seems that it is not only not beneficial for the colony but also causes the colony's isolation in the world system of science. A colony whose entire collaboration is with only one colonizer is an actor with an isolated personal network. Instead of focusing on collaboration with one of the powerful actors of the network, the former colonies should distribute this focus among all the powerful actors of the network so that it includes collaboration with regional powers. In this way, if the colony's relationship with the colonizer becomes problematic in the future, the colony can focus on collaboration with other network powers. India is an example of a country that should adopt such a policy. India's collaboration with the UK is gradually increasing. To improve its position in the network, India should pursue strategies such as strong collaboration with regional powers (especially China) and strong collaboration with the western powers of the network.

Limitations and Future Research Directions

This study was faced with two limitations regarding the data. First, the available data for each measure covered a different period, and their common period was only 16 years. Second,

the lack of data for 27 independent countries was located in the peripheral position of the IRC network throughout the period 2002-2017. All these countries had no data in at least one measure from 2002 to 2017. The latter limitation implies that if future research tries to identify factors affecting the countries' peripheral position in the IRC network, they will face problems due to the lack of data for some of these countries. Therefore, the authors suggest conducting the research to identify political, economic, social, and cultural mechanisms affecting the degree of inter-country research collaboration in the period 2002-2017. Such a study can be done using a longitudinal structural equation model (LSEM). Based on theories, paths between each pair of causal conditions can be drawn. Such a model will show which mechanisms have a significant and constant effect on increasing/decreasing the degree of IRC over time. Since, in the SEMs, the dependent variable includes all cases, removing peripheral cases with no data is not a very important issue.

Conclusion

Drawing upon the social system framework, this study identified what factors can increase the number of international research collaborations to the highest level. Through an empirical investigation of the inter-country research collaboration network (2002-2017), this study identified the minimum conditions for realizing the central position using a descriptive strategy. In other words, the results indicate that all four subsystems (including political, economic, social, and cultural) affect the growth of countries' articles. In general, the performance of the above subsystems overshadows the level of scientific interactions of countries and, as a result, their scientific productions. The results of this research show that to raise the level of these interactions in countries with a certain type of government (i. e., democratic or non-democratic), which subsystems should be given more attention?

Western democracies achieve a central position in the network when a high degree of liberal democracy, high government efficiency, and high human development are combined with high exports or at least a social element (i. e., high social similarity or high international student exchange) in them. In contrast, the central position in non-democratic nations is the product of a robust social subsystem combined with high government efficiency and high exports. In addition, this study identified the causal configurations for realizing the central position using an explanatory strategy. The only difference between the causal configurations identified with the above combinations is in the combinations containing at least one social element for Western democracies. These combinations can also include a cultural element (i. e., a high percentage of the English-language population or a high degree of scientific dominance). Cultural elements only appear in causal configurations where elements from all three other subsystems are also present.

Endnotes

1. Access to the Web of Science Core Collection Database is possible for Iranian users through Yabash digital library (at: http://yabesh.ir/).

2. Also, 27 independent states (including Andorra, Antigua and Barbuda, Bahamas, Belize, Brunei, Dominica, Grenada, Kiribati, Liberia, Liechtenstein, Marshall Islands, Micronesia, Monaco, Nauru, North Korea, Palau, Samoa, San Marino, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Somalia, the Vatican City State (Holy See), Timor-Leste, Tonga, Tuvalu, and Uzbekistan) were removed for the above reason. So, there are two categories of countries: independent and non-independent countries. We have data for most of

the independent countries (on average 165 countries per year) in all eight measures. However, for non-independent countries and 27 independent countries, we have no data at all in at least one of the eight measures (from 2002 to 2017).

3. In addition to the degree centrality, Chang et al. (2017) have proposed other network indicators to determine the network position. However, we only use the degree centrality because what matters to us is the difference in the degrees of research collaboration.

4. https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

5. http://uis.unesco.org/en/glossary-term/international-or-internationally-mobile-students

6. http://data.uis.unesco.org/#

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Appendix: The Calibration and the Results of Robustness Analysis

Table 5
The calibration thresholds and related robustness ranges

Set/Threshold	Calibration	Lower Bound	Upper Bound
Lib_Dem			
Full membership	0.6965	0.6955	0.6975
Crossover	0.4565	0.4555	0.4575
Full non-membership	0.2035	0.2025	0.2045
Gov_Eff			
Full membership	73.15	73.07	73.22
Crossover	47.97	47.95	48.05
Full non-membership	23.92	23.80	24
HDI			
Full membership	0.8155	0.8145	0.8165
Crossover	0.6795	0.6785	0.6815
Full non-membership	0.5295	0.5285	0.5305
Exp_Val			
Full membership	1007080609	968935602	1047029245
Crossover	338845355	335536935	341947182
Full non-membership	97839815.5	97105673	98824503
Soc_Sim			
Full membership	0.625	0.624	0.626
Crossover	0.435	0.434	0.436
Full non-membership	0.215	0.214	0.216
Int_Stu			
Full membership	291413	262188	320638
Crossover	127291	121475	142107
Full non-membership	37331.5	36991	37672
Eng_Lan			
Full membership	80	68	83
Crossover	30	28	33.5
Full non-membership	9	8	10
Deg_SciDom			
Full membership	6.33	6.15	8
Crossover	3.60	0.468	3.85
Full non-membership	0.18	0.175	0.19
Net_Pos			
Full membership	89842	84813	90869
Crossover	40260	40260	44013
Full non-membership	11775	10771	11775
Solution Consistency	0.917	0.932	0.914
Solution Coverage	0.592	0.583	0.606