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What kinds of countries have better innovation performance?—A country-level fsQCA and NCA study

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ABSTRACT

Innovation is critical to boosting economic growth and combating social problems. Based on national innovation systems, this study investigates how combinations of multiple factors (i.e., R&D investment, human capital, social freedom, democracy, globalization, and country affluence) lead to high national innovation performance. This study adopts fuzzy-set qualitative comparative analysis (fsQCA) to explore multiple conjunctural causations of innovation performance using a multi-source dataset of 116 countries. It identifies two configurations for high innovation performance: leveraging human capital and leveraging R&D investment. It also adopts a necessary condition analysis (NCA) to examine the necessary relationships between every condition and the outcome. NCA finds that R&D investment, globalization, and country affluence are necessary conditions for innovation performance, although they have different degrees of importance. This study advances the knowledge on national innovation performance and demonstrates how NCA can add complementary insights to the findings of fsQCA.

Introduction

Innovation has always piqued the interest of practitioners, academics, and policymakers because it plays a pivotal role in economic growth and social change (Damanpour & Schneider, 2006). Fostering innovation at all levels has become an important research topic for scholars. However, compared with numerous studies investigating innovation antecedents at the individual and organizational levels (Damanpour, 1991; West & Altink, 1996; Zheng et al., 2021), the literature exploring the drivers of country-level innovation has developed more slowly, leaving many vital questions unanswered. Contrary to country-level innovation receiving less attention in academia, many countries have attached considerable importance to it and formulated relevant policies for national innovation performance (Bloom et al., 2019; Mowery, 1998). National innovation performance refers to a country's ability to transform innovation inputs into outputs, thus generating achievements and benefits in innovative activities (Iglesias-Sánchez et al., 2019, p. 178; Zizlavsky, 2016).

The literature provides different perspectives on exploring the enablers of innovation (Lundvall, 2007; Watkins et al., 2015). However, the existing literature suffers from the following deficiencies. First, most studies understand country-level innovation from a business or market perspective. They rely heavily on the Global Innovation Index (GII) dimensions, limiting our understanding of innovation from different theoretical perspectives (Crespo & Crespo, 2016; Yu et al., 2021). For example, López-Cabarcos et al. (2021) maintain that foreign direct investment (FDI) is crucial for country-level innovation. Nevertheless, in their arguments, the impact of FDI is limited to markets and industries that receive direct foreign investment. Their conceptual frameworks do not capture the nature of innovation and only account for a limited variety of entities that conduct innovative activities. As Feldman and Kogler (2008) point out, firms' efforts are merely the visible tip of the iceberg that defines innovation activities. Many unobserved entities such as governments, universities, non-profit organizations, and other institutions are also essential to innovation. When studying innovation at the country level, the conclusions drawn from these studies are likely to be incomplete if we limit the research perspective to the market or business.

Second, there is a lack of dialogue between various theories on innovation, as most studies are based on a single theoretical perspective. National innovation systems have become the most prominent theoretical foundations (Wang et al., 2021). However, there is currently no consensus in the literature on how national innovation

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systems should be defined and measured (Fagerberg & Srholec, 2008). The researcher's discretion determines the factors they want to deploy to understand the national innovation performance. Exploring multiple theories may holistically explain innovation performance.

Third, there is a mismatch between theory and methods regarding national innovation performance (Khedhaouria & Thurik, 2017). Many studies have employed regression-based statistical techniques to explore the net effects of single factors. Net effect thinking currently dominates social science, holding that each element can independently influence outcomes. However, macro and micro theories of innovation, such as national innovation systems (Lundvall, 2007) and the ability-motivation-opportunity framework (Bos-Nehles et al., 2017), believe that innovation relies on interdependence of multiple factors. Therefore, interpreting innovation should be based on the systematic perspective of configurational thinking (Pustovrh & Jaklič, 2014). Configurational thinking sees causal conditions not as adversaries in the struggle to explain variation in the outcome but as potential collaborators contributing to the outcome (Ragin, 2008, pp. 113−114). The critical issue for studies on innovation performance is not which variable has the most substantial net effect. Rather, it is the question of how various conditions combine and whether there is only one combination or diverse combinations of conditions (causal recipes) capable of generating high innovation performance.

This study fills these research gaps as follows. First, as Lundvall (2007) puts it, the national innovation systems must help understand both micro-behavior in the core and "wider settings" within which the core operates. This study builds on the two most essential elements of innovation: knowledge and learning. It seeks to construct an explanatory framework with broader applicability to national innovation performance. Lundvall (2016, p. 6) points out that the most fundamental resource in the modern economy is knowledge; accordingly, the most crucial process is learning. The resource-based perspective stresses that innovative activities and knowledge generation depend on resources. Therefore, this study's framework incorporates R&D investment and human capital because they provide the necessary financial and human resources for innovation.

Learning is a socially embedded process that can only be understood by considering institutional and social contexts (Lundvall, 2016, p. 86). Innovation does not occur in a vacuum, and many macro-socioeconomic factors play an important role in national innovation systems (Crespo & Crespo, 2016). The institution-based perspective emphasizes the role of institutions in shaping innovation. Therefore, the framework incorporates democracy and social freedom because they represent formal and informal institutional support for knowledge creation and learning.

Moreover, innovation generation patterns vary across different settings. Globalization has challenged the traditional role of national states in supporting learning processes (Lundvall, 2016, p. 86). Globalization enables a country to learn, absorb, and imitate the innovative outputs of other countries. Country affluence is also an essential contextual factor because countries at different stages of development have different driving forces or formation paths for innovation systems (Watkins et al., 2015). This study constructs an analytical framework comprising six elements and seeks to understand how different enablers of innovation performance complement each other and lead to high innovation performance.

Second, this study adopts QCA instead of applying a regression-based technique to unravel causal complexity. This study focuses on two features of causal complexity: equifinality and conjunctural causation (Schneider & Wagemann, 2012, p. 78). An analysis of equifinality allows us to find different, mutually non-exclusive explanations of high innovation performance. Conjunctural causation implies that conditions must be combined to reveal causal recipes (Schneider & Wagemann, 2012, p. 89), enabling us to understand a single condition's role in innovation systems under specific conditions. Additionally, this study makes an innovative attempt in research methods by using necessary condition analysis (NCA). This demonstrates how NCA can provide complementary insights into fsQCA.

The remainder of this article proceeds as follows. Section 2 introduces an integrated conceptual framework to unravel the multiple driving forces of national innovation performance. Section 3 introduces research methods and presents operational definitions and descriptive statistics for each condition. Section 4 shows the results of fsQCA and NCA by using a multi-source dataset of 116 countries. Section 5 discusses the theoretical and practical insights drawn from this study and how NCA can complement the application of QCA. Finally, the main conclusions of this study are summarized.

Theoretical framework

R&D investment

As innovation became increasingly crucial in economic growth and productivity, scholars gradually became interested in exploring what drove innovation during the 1980s. The knowledge production function maintains that R&D input is the primary indicator of innovation output (Koo et al., 2020; Verba, 2020). R&D usually refers to innovative activities to develop new services or products and improve existing ones. Current literature has extensively studied the relationship between R&D investment and innovation at the firm level (Gicheva & Link, 2016; Jaffe, 1989; Link et al., 2020). However, relatively few studies have taken the country as the unit of analysis (Link, 2021; Raghupathi & Raghupathi, 2017). For example, based on World Bank aggregate data, Link (2021) finds that R&D investment positively relates to innovative behavior at the country level. Nevertheless, this relationship varies across countries at different developmental stages. Investment in R&D plays a pivotal role in innovation, as R&D can directly bring about new knowledge, products, and services. Moreover, R&D is vital for both firms and governments (Barasa et al., 2017; Raghupathi & Raghupathi, 2017). Firms' R&D expenditures can help them achieve competitiveness in a rapidly changing market. Governments' expenditures on R&D can provide incentives to foster innovative activities in the private sector and support universities and research institutions for basic and applied research. Therefore, R&D investment is an essential enabler of innovation capability as it constitutes a financial basis for innovation performance. The first proposition is as follows.

P1: R&D investment is a necessary condition for national innovation performance.

Human capital

As knowledge-intensive activities play a crucial role in economic growth and scientific innovation, scholars have gradually emphasized the importance of human capital in fostering innovation. Human capital can be described as knowledge and skills gained through training and education (Aleknavičiūtė et al., 2016). The human capital theory maintains that investment in people can enhance their productivity and learning capabilities, increasing the well-being of individuals, organizations, and society (Nafukho et al., 2004). Empirical evidence has found that innovation is one of the most striking positive effects of human capital. There are several reasons to expect high human capital to lead to innovation. First, human capital is a core prerequisite for innovative activities by accumulating and exchanging high-quality knowledge, which leads to idea combinations and new knowledge creation (Kwan & Chiu, 2015). Second, organizational members resist innovative activities and adhere to traditional regulations to gain legitimacy from stakeholders (DiMaggio & Powell, 1983). Investment in human capital enables organizational members to renew and update their capabilities, which helps break the organization's adherence to old routines (Shane, 1995). Third, in addition to generating new knowledge independently, individuals and organizations can increase innovation performance by acquiring diverse and heterogeneous expertise from external sources. Human capital can increase a country's ability to adopt technological advances abroad (Bashir et al., 2021). A country's investment in human capital provides the human resources necessary to achieve high levels of innovation performance. The second proposition is as follows.

P2: Human capital is a necessary condition for national innovation performance.

Social freedom

Innovative activities do not occur in a vacuum but are affected by social and cultural factors. Many economic growth theories assume that a certain level or type of social freedom is a critical condition for innovation (Lehmann & Seitz, 2017). Various types of individual-level freedom (e.g., job autonomy, see Orth & Volmer, 2017; freedom to express, see Chen & Hou, 2016) and organizational-level freedom (e.g., organizational climate, see Koys & DeCotiis, 1991) are positively related to innovative behavior. However, the literature documenting the association between freedom and country-level innovation has developed more slowly, although social freedom—an indicator reflecting social climate characteristics—significantly shapes individuals' and organizations' thinking and actions. There are at least three reasons for expecting social freedom to lead to innovation. First, countries with high social freedom attract and retain talented people (or creative classes) who can spur economic growth and knowledge creation through innovation (Hansen & Niedomysl, 2009). Second, a high degree of social freedom stimulates knowledge flows, diversity, creativity, and open social structures, where innovative and risk-taking behavior can be fostered (Florida et al., 2008). Third, the social capital perspective does not regard innovation as an exogenous or isolated activity but as a social event embedded in social institutions and communities that help diverse but interdependent actors interact and exchange knowledge (Landry et al., 2002; Zheng, 2010). High levels of social freedom may facilitate coworking, creativity, and knowledge spillovers (Lehmann & Seitz, 2017), creating a supportive social climate for innovation. Therefore, the third proposition is as follows.

P3: Social freedom is an enabler for national innovation performance.

Democracy

Formal institutions can also influence innovation. Innovation requires a stable domestic economic environment, material guarantees, and a free political environment that encourages personal initiatives (Gao et al., 2017). Democracy provides a supportive institutional environment for innovation. Although there are many forms of democracy, political and economic scholars agree that democracy has the following characteristics: facilitating economic freedom and protecting property rights. These characteristics eventually contribute to innovative activities by building institutions that foster scientific innovation and protect intellectual property (Gao et al., 2017; Popper, 2005; Wang et al., 2021). Democracy can indirectly influence innovation through spillover effects, such as increasing the quality of governance and promoting social progress (Bäck & Hadenius, 2008; Thompson, 2004). Popper (2005) points out that democratic countries perform better in fostering innovation; his hypothesis drives scholars to test it empirically. Gao et al. (2017) analyzed a dataset of 156 countries between 1964 and 2010 using the difference-in-differences method. They concluded that democracy has no direct positive effect on innovation, as measured by the index of patents. However, Wang et al. (2021) argue that merely using patents to measure innovation performance is flawed. They use patents and trademarks as proxies for national innovation performance and employ a generalized method of moments (GMM) to increase the validity of the empirical findings. The empirical results show that democracy is strongly positively related to innovation performance, and even a change in democracy significantly influences innovation (Wang et al., 2021). Nevertheless, they also imply that the influence of democracy on innovation might vary in different socioeconomic situations, which highlights the importance of configurational thinking (i.e., the role of democracy in innovation should be interpreted when combined with other factors). Thus, the fourth proposition is as follows.

P4: Democracy is an enabler for national innovation performance.

Globalization

Globalization is one of the most critical forces shaping economic growth and social progress. It can be described as a process of eroding national borders, integrating the national economy, culture, technology, and governance, and creating complex interdependent relationships (Dreher, 2006). National innovation systems focus on nationally bounded interactions and processes of different institutions, ignoring the potential positive effects of exchange and cooperation between countries. The diffusion of innovation theory maintains that various social system members can communicate and adopt each other's innovations; this process is called innovation diffusion (Rogers, 2003, p. 35). Therefore, one country's innovation performance is likely to be affected by the extent to which it can learn, absorb, and imitate other countries' innovations. Numerous studies have documented the impact of globalization on innovation at the country level (Bloom et al., 2016; Chang & Lee, 2010; Spulber, 2008; Zheng et al., 2019). However, previous studies usually narrow globalization to economic dimensions such as trade, which ignores countries' social and political integration processes (Zheng et al., 2019). Globalization is a multifaceted concept, including opening up to trade and capital flows, communication and exchange of ideas among different citizens, and cooperation among governments (Gygli et al., 2019). Zheng et al. (2019) provide empirical evidence to support the positive effect of globalization on innovation. They proposed three potential mechanisms to explain the impact process. First, bilateral trade promotes knowledge and technology transfers. Second, information flow creates novel research directions and diverse research paths. Third, international policy diffusion promotes reforms in administrative agencies and regulations. They adopted a multidimensional indicator to measure innovation and found a positive influence of globalization on national innovation in the least innovative countries (Zheng et al., 2019). High globalization is an essential prerequisite for innovation performance in a world where innovation increasingly depends on mutual communication and collaboration. Hence, the fifth proposition is as follows.

P5: Globalization is a necessary condition for national innovation performance.

Country affluence

Country affluence may also be a crucial contextual factor in national innovation. National innovation systems were initially used to describe variations in innovation performance among developed countries (Metcalfe & Ramlogan, 2008). However, only a few scholars have used this framework to explore innovation in developing countries (Alcorta & Peres, 1998; Metcalfe & Ramlogan, 2008; Wu et al., 2017). One important reason is that some concepts of national innovation systems may not fit the characteristics of developing countries (Crespo & Crespo, 2016). For example, Arocena and Sutz (2000) argued that many essential elements (e.g., technological and industrial institutions) of national innovation systems do not exist or are insufficient in developing countries. Developed and developing countries show different patterns of economic development and innovation processes; therefore, the driving forces of innovation might also be different (Watkins et al., 2015). Empirical studies have found that combinations of causal conditions that lead to high innovation performance in developed countries do not apply to developing countries (Crespo & Crespo, 2016; Wang et al., 2021). Therefore, the modes of generation of innovation performance may be contingent upon country affluence. Thus, the sixth proposition is as follows.

P6: Countries at different developmental stages differ in their generation mechanisms to achieve high national innovation performance.

As illustrated above, country-level innovation is a complex process that involves many factors. Fig. 1 illustrates this conceptual framework. These factors do not impact innovation performance independently; they may interact differently and form different paths toward high innovation performance. Many empirical studies have also expressed that studying innovation performance requires configurational thinking; therefore, interpreting the influence of a single factor on innovation should combine other factors. For example, in exploring the impact of democracy on innovation, Wang et al. (2021) pointed out that such an influence may vary under different socioeconomic factors, such as economic performance and globalization. Similarly, in investigating the effect of globalization on innovation, Zhang et al. (2019) found that globalization impacts OECD and APEC countries differently. Therefore, a method that fits configurational thinking is required in studies of national innovation performance.

Methodology

Method

With its focus on revealing causal complexity, QCA has recently gained increasing attention and application in business and management academia (López-Cabarcos et al., 2016; Misangyi et al., 2017; Pappas & Woodside, 2021). The logic of QCA differs substantively from that of regression-based techniques in many aspects, making it a suitable method for this study. First, instead of focusing on the net effects of every single factor, this study explores how combinations of multiple causal conditions lead to high innovation performance. QCA enables us to find various causal recipes for the same desired outcome—a situation called equifinality. Second, QCA can identify whether a condition is necessary for the desired result. A necessity statement or hypothesis (e.g., globalization is necessary for innovation performance) can only be examined by QCA or NCA. However, many scholars have confused necessity and sufficiency because they often use traditional regression-based methods to empirically test necessary but insufficient statements (Dul, 2016a). Additionally, QCA can only test relationships of necessity in kind, whereas NCA can also test necessary statements in degrees, making it an excellent complement to QCA (Vis & Dul, 2018).

Further, many traditional problems plagued by applied users of regression analytical methods (RAMs) do not cause severe threats in QCA. The first is multicollinearity. In this study, many conditions influencing innovation performance may be highly correlated, indicating that deploying RAMs is unsuitable. Multicollinearity makes it difficult to isolate the effect of one condition from another, hindering the intention of the regression analysis to explore the net effect. However, QCA does not assume the independence of the explanatory variables as an assumption (Dușa, 2020). In QCA, the problem of multicollinearity is called limited diversity, a feature of many naturally occurring phenomena (Ragin, 2008, p. 147). Many social phenomena appear in clusters and impact outcomes only in conjunction (Wagemann & Schneider, 2007). Limited diversity implies that many logically possible combinations lack empirical evidence. As complex solutions only use empirical information, they are subject to limited diversity. Limited diversity makes complex solutions intricate because little or no simplification occurs (Ragin, 2008, p. 175). Conversely, intermediate and parsimonious solutions incorporate counterfactual analysis. Therefore, they are less affected by limited diversity and preferred by most researchers.

Second, many variables causally relevant to the outcome are omitted from the model. This study's theoretical framework inevitably omits other factors causally related to innovation performance. However, this is not a severe threat to QCA because its logical basis is INUS causation (Baumgartner, 2021). INUS stands for "Insufficient but Necessary part of a condition which is itself Unnecessary but Sufficient for the result" (Mackie, 1965, p. 246). For example, when firms have ample financial resources, they can invest in R&D, promoting innovation performance. The financial resource surplus (A) and R&D investment (B) can lead to high innovation performance. R&D investment is necessary for this situation, and there would be no high innovation performance without it. Nevertheless, this set of conditions is not necessary for high innovation performance because other sets of conditions are also sufficient for the outcome. Firms may also use surplus financial resources to acquire innovative organizations and achieve high innovation performance. Combining a financial resource surplus (A) and the acquisition of other innovative organizations (C) can also lead to high innovation performance. Therefore, R&D investment is an insufficient but necessary (non-redundant) part of an unnecessary but sufficient condition for the outcome. If we only included conditions A and B in the study and omitted condition C, we cannot know that the combination of C and B also leads to the outcome. Nonetheless, we find that the combination of A and B causes high innovation performance, and this conclusion is undeniably correct. Thus, if the omitted variable is an INUS condition, we cannot determine other causes of the outcome. If the omitted variable is a necessary condition, we might ignore this critical condition, which allows all the identified sufficient solutions to work. A necessary condition implies that it is an indispensable factor for the presence of the outcome; otherwise, even the identified sufficient solutions will not produce the desired outcome. In summary, the problem of omitted

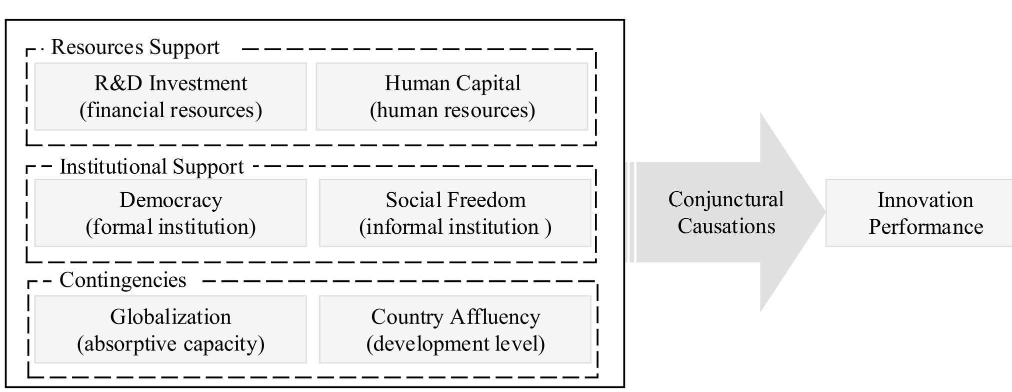

Fig. 1. Conceptual framework.

variables did not affect the correctness of the identified solutions. However, this may lead us to overlook some necessary conditions that allow the identified solution to produce the desired results.

Data and measurements

QCA uses calibrated data with values from 0−1. Calibration is a process in which raw data are transformed into membership scores in each set. This study adopts the direct calibration method and specifies three variables' anchors: the benchmark for full membership, crossover point, and full non-membership. Membership scores should reflect external standards based on substantive knowledge and the existing literature (Ragin, 2008, p. 208). When external standards and substantive knowledge are unavailable, a mechanistic calibration method based on the percentiles of the sample is preferred and widely adopted by scholars (De Crescenzo et al., 2020). Therefore, democracy and country affluence were calibrated using external standards. For the other variables without established external standards, this study used mechanistic calibration and assigned the 95th, 50th, and 5th percentiles of the original data as the thresholds for fully in, crossover, and fully out of the sets, respectively (Pappas & Woodside, 2021; Woodside, 2013). The calibration anchor distinguished relevant and irrelevant variations (Ragin, 2008, p. 33). It is imprudent to erase excessive variance in the raw data without substantive knowledge. Therefore, the 95th-50th-5th percentile calibration was employed because it retained more differences in the raw data. Conversely, the 75th-50th-25th percentile calibration method reduced the variance in the raw data. For example, the difference between the 75th and 100th cases is almost eliminated in the calibrated data because they are all considered fully in a set—differences in the raw data are considered irrelevant to the degree of membership in a set.

R&D investment was measured by the sub-index of R&D from the 2019 GII report. This sub-index captures the level and quality of R&D activities, which considers researchers, R&D expenditure, and the quality of research institutions.

Human capital was measured using the sub-index of tertiary education from the GII report in 2019. This sub-index measures the performance of higher education, which considers tertiary enrolment, the percentage of tertiary graduates in science, and the inbound mobility of tertiary students.

Social freedom was measured by a proxy variable: the Gay Travel Index (GTI) published by the SPARTACUS World in 2019. This index measures the legal situation and living conditions of queer community members in the respective country. Many scholars assume that gays would choose relatively open-minded and tolerant places for newcomers and alternative ways of living and thinking (Florida, 2014; Inglehart et al., 2008). Therefore, a high degree of gay friendliness indicates a high degree of individual freedom and social tolerance. Lehmann and Seitz (2017) adopted the GTI to measure social freedom.

Democracy was measured using the Democracy Index published by the Economist Intelligence Unit in 2019. This index measures pluralism, civil liberties, and political cultures. The Economist Intelligence Unit established relevant criteria, holding that the scores of 8, 6, and 4 in the index are the thresholds for full democracy, hybrid regimes, and authoritarian regimes, respectively. Therefore, 8, 6, and 4 were assigned as the benchmarks for fully in, crossover, and fully out of this set, respectively.

Globalization was measured using the KOF Globalization Index of 2019 (Gygli et al., 2019). This composite index measures globalization for every country along the economic, social, and political dimensions, combining *de facto* and *de jure* globalization.

Country affluence was measured by gross national income (GNI) per capita in 2019, as published by the World Bank. The established standards made by the World Bank set the thresholds for high-, middle-, and low-income countries as $46038, $5523, and $688, respectively. Therefore, $46038, $5523, and $688 were assigned as benchmarks for fully in, crossover, and fully out of this set, respectively.

Table 1
Calibration anchors of each fuzzy set.

Sets	Calibration anchors		
	Fully in	Crossover	Fully out
R&D investment	73.88	9.1	0
Human capital	57.35	32.15	6.4
Social freedom	9	0	-9.25
Democracy	8	6	4
Globalization	88.66	70.24	50.84
Country affluence	46038	5523	688
Innovation performance	50.55	24	10.08

Innovation performance was measured using the innovation output sub-index from the 2020 GII report. This indicator comprises knowledge, technology, and creative outputs, providing information about the performance of innovative activities within each economy (Cornell et al., 2020). Knowledge creation, impact, and diffusion are the three dimensions of knowledge and technology outputs. Intangible assets, creative goods and services, and online creativity constitute the creative output.

A total of 116 countries have data on all variables; their information can be found in the Appendix. However, cases with a score of 0.5 in any condition will be excluded from the truth table analysis in QCA. Following established practices, each membership score with a value of 0.5 is recalibrated by adding a small constant (0.001) to avoid this problem (Du & Kim, 2021; Fiss, 2011). Table 1 presents the calibration anchors for each fuzzy set. All data and results from the analyses are openly available on the OSF platform: https://osf.io/z7gbc/.

Analysis

Descriptive analysis

Table 2 presents a descriptive analysis of each variable. All the variables were positively correlated with the outcome.

Necessity analysis

QCA is a set-theoretical method that separately tests sufficient and necessary relationships. This study first conducts a necessity analysis to examine whether any single condition is necessary for high innovation performance in the fsQCA 3.0. Table 3 shows that only country affluence passes the consistency threshold of 0.9, indicating that high country affluence is necessary for high innovation performance.

Second, as mentioned before, NCA can analyze necessity relationships in kind and degree, helping to answer questions like "what degree of the antecedent (e.g., country affluence) should be at least if

Table 2
Descriptive statistics of each variable.

	1	2	3	4	5	6	7	Mean	SD
1.RD	1							21.97	24.67
2.HC	0.52**	1						31.86	15.48
3.SF	0.56**	0.30**	1					-0.42	6.18
4.DEM	0.56**	0.28**	0.76**	1				6.14	2.04
5.GLO	0.71**	0.67**	0.63**	0.65**	1			70.35	12.107
6.CA	0.79**	0.53**	0.57**	0.59**	0.72**	1		19076	21428
7.IP	0.86**	0.57**	0.64**	0.64**	0.81**	0.78**	1	26.07	13.10

Note: $^{**}p<0.01$, RD= R&D investment, HC= human capital, SF= social freedom, DEM= democracy, GLO= globalization, CA= country affluence, IP= innovation performance.

Table 3
Analysis of necessity for high innovation performance.

Sets of conditions	Consistency	Coverage
R&D investment	0.857	0.851
~ R&D investment	0.461	0.401
Human capital	0.826	0.770
~ Human capital	0.490	0.450
Social freedom	0.798	0.774
~ Social freedom	0.496	0.440
Democracy	0.853	0.717
~ Democracy	0.364	0.376
Globalization	0.899	0.812
~ Globalization	0.425	0.404
Country affluence	0.906	0.775
~ Country affluence	0.418	0.422

Note: ~ indicates the absence of or a low level. For example, ~ democracy is the absence of democracy or low democracy (i.e., membership score in the set of democracy < 0.5).

one country wants to achieve a specific level of innovation performance?” Necessity analysis in NCA fundamentally differs from the fsQCA approach; this difference often leads to NCA identifying additional necessary conditions than fsQCA (Dul, 2016a). The two methods do not compete; instead, they provide complementary insights. Therefore, NCA should not be used as a tool for robustness testing of QCA necessity analysis (Du & Kim, 2021) but as a complementary tool for QCA necessity analysis. NCA can use both calibrated and raw data (Dul, 2016b). A necessary condition analysis was conducted by R package “NCA” with calibrated data for two reasons. First, this study focuses on set relations (i.e., sufficiency and necessity); the calibrated configurational data are more meaningful and fit better with set relationships. Second, using the same data can show us what additional insights NCA can bring to fsQCA through necessity analysis in degree.

NCA draws a ceiling line on the top of the data in an XY scatter plot, and the space above the ceiling line (i.e., the upper left corner) indicates that high levels of Y are not possible with low levels of X (Dul et al., 2020). Fig. 2 shows the scatter plots with ceiling lines. The space in the upper left corner relative to the total space with observations reflects the extent of the constraint that X poses on Y; the larger the space, the more X constraints Y (Dul et al., 2020). NCA uses two techniques to draw ceiling lines: ceiling envelopment with a free disposal hull (CE-FDH) and ceiling regression with a free disposal hull (CR-FDH). CE-FDH is preferred under the following conditions: (a) the variables are dichotomous; (b) the variables are discrete with a small number of variable levels (e.g., < 5); (c) a straight ceiling line does not properly represent the data around the ceiling line; (d) smoothing significantly reduces the size of the ceiling zone (Dul, 2016a). As shown in Fig. 2, the data around the straight ceiling line are jumpy, indicating that a straight ceiling does not fit the data points well. Thus, this study reports the results generated by the CE-FDH.

Dul et al. (2020) recommend that whether a condition is necessary depends on two criteria. First, the effect size should pass the 0.1 threshold level; otherwise, the effect size should be too small to make sense. Second, the *p*-value based on the permutation test should be smaller than 0.05 to demonstrate that the effect size is not the result of random chance. NCA results in Table 4 show that R&D

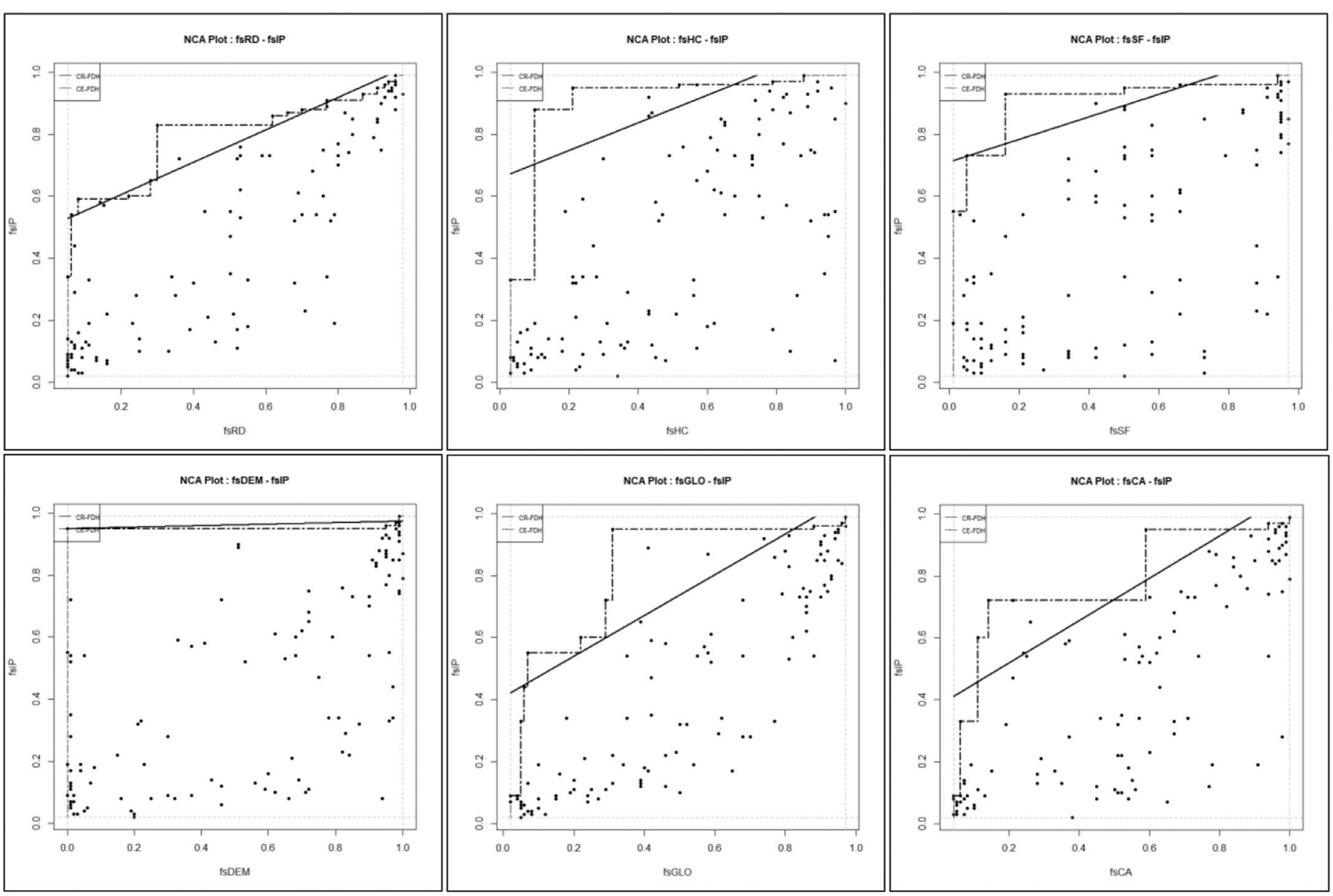

Fig. 2. Scatter plots with ceiling lines. CR-FDH generates straight lines (i.e., solid lines), and CE-FDH generates the piecewise lines (i.e., dashed lines).

Table 4
Results of necessary condition analysis.

Condition	Method	Accuracy	Effect size	*P*-value
R&D investment	CE-FDH	100%	0.202*	0.000
Human capital	CE-FDH	100%	0.086*	0.000
Social freedom	CE-FDH	100%	0.087*	0.000
Democracy	CE-FDH	100%	0.040*	0.032
Globalization	CE-FDH	100%	0.177*	0.000
Country affluence	CE-FDH	100%	0.214*	0.000

Note: The ceiling technique that produces the results is CE-FDH. Accuracy is the number of cases on or below the ceiling lines divided by the total number of cases multiplied by 100%. The effect sizes were based on 10,000 random samples generated by an approximate permutation. The extent to which a condition is necessary is expressed with the effect size d (d = the size of the space above the ceiling/the total space where cases are observed). General benchmark for effect size: $0 \leq d < 0.1$ "small effect," $0.1 \leq d < 0.3$ "medium effect," $0.3 \leq d < 0.5$ "large effect," and $d \leq 0.5$ "very large effect."). * $p < 0.05$ level.

investment, globalization, and country affluence are necessary for high innovation performance, although they are of different importance (i.e., they have different effect sizes). The results of fsQCA and NCA partially supported P1 and P5 but not P2. Some theories and empirical studies conclude that R&D investment, globalization, and country affluence contribute to innovation (i.e., sufficiency relationships). However, NCA found that these three factors are also necessary for innovation performance because high innovation performance is impossible when these factors are low. Therefore, NCA allows researchers to build and test causal necessity relationships (Dul, 2021).

A necessary condition is a bottleneck for the outcome to exist, and other conditions cannot compensate for the absence of the necessary condition (Dul, 2016a). Table 5 displays the bottleneck table of the three significant conditions necessary to analyze the necessary relationships in degrees. The bottleneck table allows us to make necessary statements in degrees. "NN" means X is not necessary for a particular value of Y: one country can achieve the value of Y with any value of X. For example, any level of R&D investment is unnecessary if one country only wants to achieve a membership score of 0.3 in innovation performance. For a particular value of innovation performance, the conditions in the bottleneck table must be met; otherwise, this particular value of innovation performance is impossible. For instance, R&D investment > 0.77 is necessary for innovation performance > 0.9. With 0.77 in R&D investment, the maximum score of innovation performance that one country can achieve is 0.9. NCA also captures variations in degree; therefore, NCA is not a competing method for QCA's analysis of necessity. Instead, it provides additional insights into the results of fsQCA.

Table 5
Bottleneck table.

Innovation performance	R&D investment	Globalization	Country affluence
0.02	NN	NN	NN
0.1	NN	0.05	0.06
0.2	NN	0.05	0.06
0.3	NN	0.05	0.06
0.4	0.06	0.06	0.11
0.5	0.06	0.07	0.11
0.6	0.22	0.22	0.11
0.7	0.3	0.29	0.14
0.8	0.3	0.31	0.59
0.9	0.77	0.31	0.59
0.99	0.96	0.97	1

Note: The bottleneck table indicates the required levels of the necessary conditions for different levels of innovation performance. NN means "Not necessary." The minimum and maximum values of innovation performance are 0.02 and 0.99, respectively.

Sufficiency analysis

A sufficiency analysis was conducted by using a frequency benchmark ≥ 1, raw consistency ≥ 0.80, and proportional reduction in inconsistency (PRI) cutoff ≥ 0.60 (Patala et al., 2021). Unlike previously applied users of QCA who favor intermediate solutions, this paper reports parsimonious solutions based on two grounds. First, several recent methodological studies on QCA recommend reporting parsimonious solutions instead of intermediate solutions (Baumgartner, 2015; Baumgartner & Thiem, 2020; Thiem, 2019). For example, Baumgartner (2015) showed that intermediate solutions could not be interpreted causally because they contain redundant elements. Based on a series of tests, Baumgartner and Thiem (2020) proved that only parsimonious solutions are guaranteed to be correct, whereas QCA is incorrect when generating conservative and intermediate solutions. Thiem (2019) also explains why complex and intermediate solutions frequently commit causal fallacies, whereas parsimonious solutions do not seem to be affected by the risks of moving away from the truth. Second, parsimonious solutions are closer to the minimally or redundancy-free sufficient conditions. The consistencies of the parsimonious solutions are above the recommended threshold, indicating that they are already sufficient conditions for the outcome. Conversely, intermediate and complex solutions may include redundant conditions. Redundant conditions are not difference-makers; thus, they should not be considered causes. If QCA solutions contain redundant or nonessential elements that make no difference to the outcome, they cannot be causally interpretable (Haesebrouck & Thomann, 2021).

Table 6 shows the two parsimonious solutions using conventional notations: a black circle (i.e., "•") indicates the presence of the condition, and a blank space indicates that the presence or absence of conditions does not matter (Fiss, 2011). Countries with membership scores greater than 0.5 in both the solution and outcome can be found in the Appendix. In fsQCA, the absence of the condition (e.g., low innovation performance) means a set membership score < 0.5, and the presence of the condition (e.g., high innovation performance) means a set membership score > 0.5. Based on the bottleneck table in Table 5, three conditions are necessary for high innovation performance (i.e., innovation performance > 0.5): R&D investment > 0.06, globalization > 0.07, and country affluence > 0.11. Other conditions cannot compensate for the absence or low levels of the necessary conditions. Thus, the three specific values of the necessary conditions must be met; otherwise, the sufficient configurations for high innovation performance identified by fsQCA will not produce the desired outcome. Following Dul (2020), the three necessity requirements are added to the QCA sufficiency result.

Table 6
Sufficient configurations for high innovation performance.

Configurations	High innovation performance		Necessity requirement
	S1	S2	
Resources			
R&D investment		•	> 0.06
Human capital	•		
Institutions			
Social freedom	•		
Democracy	•	•	
Contingencies			
Globalization		•	> 0.07
Country affluence	•		> 0.11
Raw coverage	0.630	0.713	
Unique coverage	0.046	0.129	
Consistency	0.936	0.946	
Solution coverage	0.760		
Solution consistency	0.924		

Note: A black circle (i.e., "•") indicates the presence of the condition, and a blank space indicates that the presence or absence of conditions does not matter.

Sufficiency analysis identified two distinct influence mechanisms for high innovation performance: *leveraging human capital* (S1) and *leveraging R&D investment* (S2). S1 has a consistency of 0.936 and a raw coverage of 0.630, indicating that this configuration can explain 63% of the membership scores in the set of high innovation performance. S2 has a consistency of 0.946 and can explain 71.3% of the outcome membership scores. Each configuration comprises ingredients from resources and institutions and operates only in specific settings. The results reveal how resource and institutional elements reinforce one another for high innovation performance in different contexts.

S1 shows that a developed country can achieve high innovation through high human capital, social freedom, and democracy. Therefore, P3 is supported. Human capital is a core prerequisite for innovation because well-educated people can engage in innovative activities (Kwan & Chiu, 2015). High human capital enables people to change, learn, improve, adapt to rapidly changing conditions (Aleknavičiūtė et al., 2016), and effectively absorb and organize knowledge to innovate (Lenihan et al., 2019). Human capital is sensitive to the institutional environment; therefore, formal and informal institutional support is needed. Social freedom fosters open-mindedness toward new ideas and influences, enables collective learning, and encourages individual initiatives (Florida, 2014). Meanwhile, democracy creates formal institutional support for innovative activities. This combination works only when the country's affluence is high. This is because human resources are liquid; people would seek appropriate places that can best leverage their knowledge. Developed countries have numerous scientific and technical organizations that can provide suitable positions to retain intellectuals (Lundvall, 2007). Conversely, investing in human capital is relatively risky for developing countries because they provide relatively fewer opportunities and positions for intellectuals to innovate and are less likely to retain them. Arguably, this configuration shows how to utilize human capital for high innovation performance; thus, the influence mechanism was labeled *leveraging human capital*.

According to S2, high R&D investment, democracy, and globalization can lead to high innovation performance. Therefore, P4 is supported. The primary purpose of R&D is to generate new knowledge and develop new products and processes. Thus, R&D investment has always been directly linked to innovation performance (Fagerberg & Srholec, 2008; Verba, 2020). However, the role of R&D investment depends on several institutional factors such as consistent policy support for innovation, economic freedom, property rights protection, good governance, and political stability (Gao et al., 2017; Gerring et al., 2005; Samara et al., 2012; Wang et al., 2021). Democratic countries are more likely to fulfill these institutional factors. Democracy facilitates the transformation of R&D investment into innovation outputs by stimulating technical progress, improving entrepreneurial activities, and incentivizing inventors to participate in innovation (Kanwar & Evenson, 2003; Wang et al., 2021). In addition to formal institutional support, R&D investment achieves its intended purpose only when globalization is high. This is because high globalization stimulates the mobility of knowledge, technology, and skilled labor, enabling R&D to remain at the top of trends and updates to generate new knowledge (Zheng et al., 2019). Otherwise, R&D investments can generate repetitive, outdated, and futile knowledge. This configuration shows how to achieve high innovation performance through R&D investment; thus, the influence mechanism was labeled *leveraging R&D investment*.

The overall solution coverage was 0.760, indicating that the two configurations explained 76% of the membership score. Coverage gauges a causal combination's practical importance or relevance (Ragin, 2008, p. 44). As S2's coverage is higher than S1's, S2 explains more membership scores of high innovation performance; therefore, it has more important theoretical and practical implications.

Table 7
Permutation tests of two configurations.

Configurations	Consistency (observed)	95% CI of Consistency (permuted)	*p*-adj
S1	0.936	[0.511, 0.719]	0.000
S2	0.946	[0.444, 0.688]	0.000

Note: The number of iterations is 10000. CI= confidence interval. The *p*-value adjustment method used was the Holm test.

Robustness analysis

Although QCA has become an increasingly prominent method for investigating causal complexity, many scholars have questioned the correctness of QCA results (Baumgartner & Thiem, 2020; Lucas & Szatrowski, 2014). One of the most severe threats to fsQCA results is rooted in Boolean minimization, which automatically produces the aggregation bias. Braumoeller (2017) points out that aggregation bias produces false-positive subset relationships, despite random data. Although QCA does not involve statistical significance in the data analysis process, it is ideal and helpful to use a statistical test that enables researchers to check whether the observed QCA relationships are spurious (Braumoeller, 2015a). Therefore, a permutation test with the number of iterations of 10000 was conducted using the R package "QCAfalsePositive" (Braumoeller, 2015b) to reject the possibility that QCA solutions may result from random chance. Table 7 displays the permuted 95% confidence intervals for the degree of consistency. All 95% confidence intervals based on permutations did not include observed raw consistencies, indicating that the two configurations identified by QCA are unlikely to result from random chance.

Additionally, the threat to QCA can also result from the parameter setting: changes in the calibration anchors can lead to substantively different results. Five variables without external standards were recalibrated using the 75th-50th-25th anchor before reconducting the sufficiency analysis. QCA generates four parsimonious configurations: high human capital and social freedom (S3); high globalization and R&D investment (S4); high democracy, human capital, and country affluence (S5); high democracy, human capital, and R&D investment (S6)[1]. Overall, the new configurations are more parsimonious than the old ones because changing the calibration anchors erased more differences among cases, making it possible to pass the consistency threshold with fewer conditions. Many (combinations of) conditions are equivalent to achieving this outcome. For instance, according to S5 and S6, R&D investment and country affluence are equivalent in leveraging human capital; a potential reason could be that both can provide opportunities for talented people to innovate.

Two pieces of evidence were used to illustrate the robustness of the results. First, the influence mechanisms remain qualitatively unchanged. This is because the four new configurations always need to leverage either human capital or R&D investment to achieve high innovation performance, which is in line with previous findings. Second, S1 and S2 were tested for the sufficiency of the newly calibrated data. Their consistencies passed the desired thresholds, indicating that they were still sufficient configurations for high innovation performance despite changing the calibration anchors.

[1] In the sufficiency analysis, some prime implicants are tied. The configuration "democracy*human capital*social freedom*country affluence*R&D investment" was kept instead of "democracy*human capital*social freedom*~globalization*R&D investment." This is because, theoretically, the absence of globalization cannot contribute to high innovation performance.

Discussion

Contributions

This study makes several contributions to the national innovation performance field. First, many previous studies have explored the net effect of critical factors on country-level innovation. However, this net effect approach contradicts the fact that innovation is a complex process that requires the interaction of multiple factors. The results support equifinality by showing that different conditions may form different, mutually non-exclusive causal recipes for the same desired outcome (Schneider & Wagemann, 2012, p. 5). This study found at least two equivalent pathways for boosting national innovation performance. S1 and S2 show how a country can leverage human capital or R&D investment to achieve high innovation performance. This study supports the view that multiple enablers of innovation systems are needed to produce high innovation performance (Metcalfe & Ramlogan, 2008), helping us understand the different influence mechanisms of high innovation performance.

Second, in addition to the two sufficient configurations, this study identifies three necessary conditions that provide more nuanced implications. Certain levels of R&D investment, globalization, and country affluence are necessary conditions for high innovation performance. Most studies do not incorporate globalization into their conceptual frameworks to explain national innovation performance. However, this study found that globalization is a necessary condition restricting high innovation performance levels. This finding supports the notion that the role of national innovation systems has fundamentally changed due to globalization (Lundvall, 2016, p. 100). Further, country affluence is the most important necessary condition because its effect size is the largest, indicating that economic development is a critical prerequisite for innovative activities. High innovation is impossible in countries without a certain level of economic development.

Third, this study distinguishes between sufficiency and necessity causalities because they have different theoretical and practical implications. However, most empirical studies and theories confuse sufficiency with necessity. For a sufficient condition, the best strategy is to achieve a high level because a sufficient condition can guarantee the desired outcome (i.e., “if X, then Y”). Nevertheless, the most cost-effective strategy for a necessary condition is to avoid a low level because the desired outcome is impossible without a certain level of the necessary condition (i.e., “No Y without X”). The outcome entails both sufficiency and necessity. For example, S2 suggests that combining the three conditions is sufficient for the outcome and that the presence or absence of country affluence does not matter. Nonetheless, NCA indicates that a membership score in the set of country affluence > 0.11 is necessary to achieve high innovation performance; otherwise, this configuration will not lead to the desired outcome. This finding supports the argument of Vis and Dul (2018) that with its ability to make necessary statements in degree, NCA can complement fsQCA by yielding more precise or complete results.

Finally, this study provides practical implications for government officials and policymakers from countries at different stages of development. All countries must first meet the required levels of each necessary condition that allows the desired levels of the outcome to exist. Certain levels of R&D investment, globalization, and country affluence are necessary conditions that must be met. Otherwise, they could become bottlenecks and hinder the occurrence of high innovation performance because other determinants cannot compensate for the absence of a necessary condition. Countries can then invest their resources into configurations that best suit them to achieve high innovation performance. Leveraging human capital (S1) or R&D investment (S2) is feasible for higher-income countries. Conversely, the choice of lower-income countries is somewhat limited because only leveraging the R&D investment strategy (S2) seems feasible. This finding supports the notion that innovation promotion systems differ among countries at different development stages (Watkins et al., 2015). However, higher-income countries may share a similar innovation system. Therefore, P6 is partially supported.

Limitations and future research

Although this study provides new insights into innovation research, it has several limitations that provide opportunities for future research. First, as discussed before, the two pathways cannot cover all the configurations that produce high innovation performance because of omitted variables. Different theoretical perspectives may provide different views on the causal recipes of innovation performance (Zheng et al., 2021). Future research could explore different pathways to innovation from other perspectives. Second, this research is cross-country; some variables may have measurement errors because of indirect measures. Future studies should explore more diverse and precise methods. Third, this study measures innovation performance using the innovation output sub-index of the GII, which comprises knowledge and technology outputs and creative outputs. However, some countries may perform better in knowledge and technology output, while others may perform better in creative outputs. An interesting research direction is distinguishing between these two innovation outputs.

Conclusions

This study examines how multiple factors combine to produce high innovation performance at the country level based on an integrated theoretical framework. From a configurational perspective, fsQCA reveals two mutually non-exclusive configurations of high innovation performance. By combining QCA and NCA, this study uncovers three necessary conditions for innovation and demonstrates how it can provide additional insights for fsQCA. In conclusion, this study contributes to the innovation literature and mixed-method research field.

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Declaration of Competing Interest

The author declares no conflict of interest.

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Appendix

Table A.1 displays the 116 countries covered in this paper. Table A.2 details the countries with membership scores greater than 0.5 in the solution and outcome.

Table A.1
The 116 countries are covered in this paper.

Albania	China	Hong Kong	Madagascar	Paraguay	Switzerland
Argentina	Colombia	Hungary	Malawi	Peru	Tajikistan
Armenia	Costa Rica	Iceland	Malaysia	Philippines	Tanzania
Australia	Croatia	India	Malta	Poland	Thailand
Austria	Cyprus	Indonesia	Mauritius	Portugal	Togo
Azerbaijan	Czech Republic	Iran	Mexico	Qatar	Tunisia
Bahrain	Denmark	Ireland	Moldova	Romania	Turkey
Bangladesh	Dominican	Israel	Mongolia	Russia	Uganda
Belarus	Ecuador	Italy	Montenegro	Rwanda	Ukraine
Belgium	Egypt	Jamaica	Morocco	Saudi Arabia	United Arab Emirates
Benin	El Salvador	Japan	Mozambique	Senegal	United Kingdom
Bosnia and Herzegovina	Estonia	Jordan	Namibia	Serbia	United States of America
Botswana	Ethiopia	Kazakhstan	Nepal	Singapore	Uruguay
Brazil	Finland	Kenya	Netherlands	Slovakia	Vietnam
Bulgaria	France	Kuwait	New Zealand	Slovenia	Zambia
Burkina Faso	Georgia	Kyrgyzstan	Nigeria	South Africa	Zimbabwe
Cambodia	Germany	Latvia	Norway	South Korea	
Cameroon	Ghana	Lebanon	Oman	Spain	
Canada	Greece	Lithuania	Pakistan	Sri Lanka	
Chile	Honduras	Luxembourg	Panama	Sweden	

Table A.2
Countries with a membership score greater than 0.5 in the solution and outcome.

Solutions	Countries
S1 (the combination of human capital, social freedom, democracy, and country affluence)	Austria (0.95,0.85), Finland (0.92,0.94), United Kingdom (0.92,0.97), New Zealand (0.91,0.74), Germany (0.91,0.95), Switzerland (0.88,0.99), Australia (0.88,0.75), Ireland (0.83,0.93), France (0.82,0.92), Estonia (0.79,0.87), Portugal (0.79,0.77), Sweden (0.79,0.97), Denmark (0.78,0.94), Czech Republic (0.77,0.88), Canada (0.75,0.85), Spain (0.75,0.8), Luxembourg (0.74,0.91), Slovenia (0.73,0.7), Belgium (0.65,0.84), Italy (0.64,0.85)
S2 (the combination of R&D investment, democracy, and globalization)	Sweden (0.96,0.97), Switzerland (0.96,0.99), Denmark (0.95,0.94), Germany (0.95,0.95), Finland (0.94,0.94), United Kingdom (0.94,0.97), Netherlands (0.93,0.96), France (0.93,0.92), Austria (0.91,0.85), Belgium (0.91,0.84), Canada (0.91,0.85), Norway (0.9,0.79), United States of America (0.88,0.96), Australia (0.87,0.75), Ireland (0.87,0.93), Italy (0.84,0.85), Spain (0.84,0.8), South Korea (0.81,0.93), Japan (0.8,0.88), Malaysia (0.8,0.73)

Note: The first number in parentheses indicates the membership score in the solution set, and the second number is the membership score in the outcome set (i.e., innovation performance). For example, "Austria (0.95,0.85)" means Austria scored 0.95 in the set of S1 and 0.85 in the set of high innovation performance.

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