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Jan Dul

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How to sample in necessary condition analysis (NCA)

Jan Dul

Rotterdam School of Management,
Erasmus University Rotterdam,
Rotterdam, the Netherlands
Email: jdul@rsm.nl

Abstract: Necessary Condition Analysis (NCA) is a novel method that gained popularity in international business and management research in recent years. It examines cause-effect relationships in terms of necessity, where *X* is necessary for *Y*, expressed as 'if not *X* then not *Y*' in nearly all cases. This stands in contrast to conventional probabilistic causality which suggests 'if *X* then probably *Y*' in a group of cases. NCA accepts two sampling approaches: purposive sampling frequently employed in qualitative research, and probability sampling, commonly used (or assumed) in quantitative research. With dichotomous variables, purposive sampling of a small number of cases showing the outcome, can identify a necessary condition. To identify a necessary condition in a population, probability sampling and NCA's statistical test for estimating the *p*-value can be used. This allows conducting NCA's statistical power test to estimate the minimum required sample size for identifying a necessary condition when it exists.

Keywords: NCA; necessary condition analysis; purposive sampling; probability sampling; statistical power; case selection; sample size; qualitative research; quantitative research.

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Biographical notes: Jan Dul is professor of Technology and Human Factors at Rotterdam School of Management, Erasmus University, the Netherlands. He has a background in the technical, medical and social sciences. His research interests include human factors (ergonomics) for studying the interaction between people and the physical and social environment to enhance performance and well-being. He is the (co)author of more than 200 academic publications. He has a special interest in empirical research methodology. He is the founder of Necessary Condition Analysis (NCA) and wrote about the method in for example, *Organisational Research Methods* and *Sociological Methods & Research*, and in two books: *Conducting Necessary Condition Analysis* (Sage) and *Advances in Necessary Condition Analysis* (online).

1 Introduction

Necessary Condition Analysis (NCA) is a method that studies phenomena from the perspective of necessity rather than probability (Dul, 2016b). A causal factor may not only increase the probability of the outcome, it can also be a necessary condition for the outcome. This means that without a certain level of the causal factor, the effect will not occur in nearly all cases. This is independent of the rest of the causal structure. The absence of the right level of the causal factor cannot be compensated by other causal factors, such that the necessary condition will be a bottleneck if the right level is absent.

The international business and management (IB&M) research community has quickly adopted NCA as a new approach for doing research. In contrast to many other new methods, NCA is generic, broadly applicable, easy to understand and use, and freely available such that the method has low translational and complexity distance (Miller et al., 2021). NCA offers a different view on causality thus allowing theoretical and methodological triangulation (Nielsen et al., 2020). NCA can be used in qualitative and quantitative research and for theory building and testing, thus serving Knight et al.'s (2022, p.50) call for a pluralistic approach in IB&M research with 'qualitative and quantitative data for exploratory and confirmatory theory development'.

Several empirical articles have already appeared using NCA in IB&M research. Bolívar et al. (2022) find that access of MNEs to resources in a network of organisational alliances is necessary for speed of international expansion. Li et al. (2023) studied whether specific amalgamation, ambidexterity and adaptability factors are necessary for rapid international growth of Indian multinational MNE's but did not find that any of these factors were required. Kardell et al. (2023) found that trust and knowledge-sharing are necessary for performance and satisfaction in virtual teams. Richter et al. (2021) study global virtual teams and find that cultural intelligence in a team is necessary for the team's social integration and performance. Hermans et al. (2024) identified two strategic capabilities, entrepreneurial orientation and marketing and sales capabilities as necessary conditions for the internationalisation of Latin American firms.

Apart from these examples of actual NCA applications in the IB&M field, several authors in this field stress the value of using NCA and recommend using the method in future research (e.g., Aguinis et al., 2020; Alon et al. 2023; Fainshmidt et al., 2020; Richter and Hauff, 2022; Richter et al. 2022; Schmuck et al., 2022; Zahoor et al., 2023). For example, Aguinis et al. (2022, p.1602) stated that 'NCA can help future researchers gain a better understanding of causal effects when examining a particular outcome', and Richter and Hauff (2022) pointed to many articles that make theoretical necessity statements. Examples include the necessity of factors that are related to ownership, location and internalisation advantage for foreign direct investment success or for internationalisation success; the necessity of experience, market knowledge and dynamic capabilities factors for internationalisation success; the necessity of transaction cost and location factors for foreign entry mode; and the necessity of knowledge-sharing and transfer, creativity a shared language and network ties for successful foreign operations and innovation. Most of such theoretical statements in the IB&M literature have not been tested, or tested only with an inappropriate, regression-based, method (theory-method misfit). These examples show that there is a high potential for conducting NCA for testing existing or new necessary condition hypotheses.

Given this potential, IB&M researchers with different backgrounds may be interested in using NCA in their studies. A question that is commonly raised when setting up an NCA study is: 'What is a proper sample size for conducting NCA?' The short answer is: 'at least one, but the more the better'. The five mentioned studies that apply NCA in IB&M research are all quantitative studies with samples sizes of 131, 160, 364, 263 and

27 cases, respectively. A typical sample size in quantitative IB&M research is 180 (Yang et al., 2006). For the design of new studies, it is unknown if these samples sizes are large enough for a powerful quantitative study that can find the necessary condition when it is present.

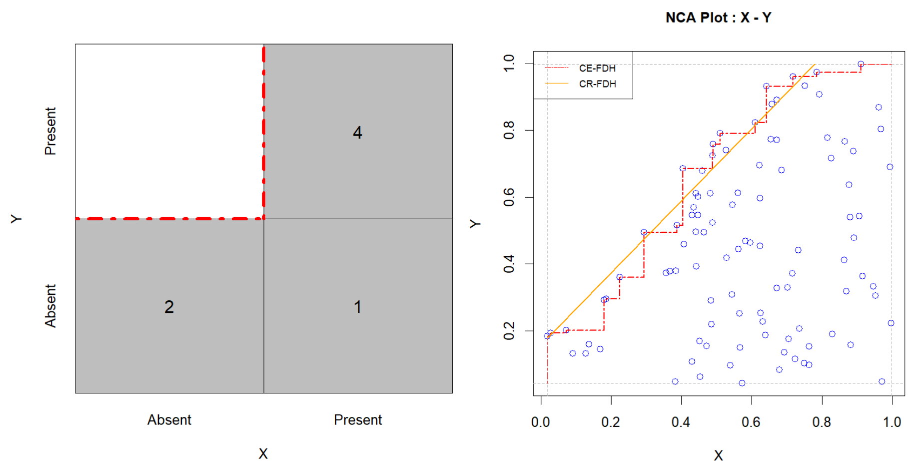
This Method note explains NCA's power analysis to estimate the sample size that is needed for a well powered quantitative NCA study. Although this has not yet been done in IB&M research, NCA can also be applied in qualitative studies where sample sizes are normally small. Qualitative research requires a different sampling strategy (usually called 'case selection') in which not the quantity, but the quality, of the sample is critical. This note explains NCA's purposive sampling approach to facilitate qualitative researchers to identify necessary conditions in a small number of cases. For the reader who is not familiar with NCA, first a short summary is given. A comprehensive explanation of the NCA approach can be found elsewhere (Dul, 2020, 2021; Dul et al., 2023).

2 NCA in brief

This section briefly summarises NCA. The four basic steps of NCA are: (1) formulating a theoretical necessity expectation (hypothesis), (2) gathering data, (3) data analysis and (4) communication of results. The first step is required to be able to make a causal claim of an observed data pattern. The causal claim can be expressed as a hypothesis describing why X is necessary for Y and why X is present before Y (temporal requirement of causality). In explorative research step 1 must be done after step 3. NCA does not have new requirements for the data other than that the data must be reliable, valid and meaningful (step 2). Data is only input to NCA. NCA accepts a wide range of meaningful data obtained in qualitative or quantitative research. These data may comprise qualitative scores, variable scores that are directly measured or latent variable scores obtained from factor analyses or from a measurement model in structural equation modelling. Additionally, NCA can handle set membership scores, which are employed in QCA. The data can be either newly collected data or archival data. Re-utilising existing data is an efficient way of examining a phenomenon with a novel causal perspective (Dul et al., 2024).

NCA's only data requirement is that X and Y have scores (have values or levels). In qualitative research, findings may be transformed into dichotomous scores using words like 'presence/absence' or low/high. It is also possible to distinguish more 'levels@, for example 'low/middle/high'. In quantitative research the scores are numeric, where the score can have few or many discrete levels or can be continuous. NCA's data analysis (step 3) consists of making and evaluating XY plots and quantifying the 'necessity effect size' and other NCA parameters. In qualitative research the data are often represented by a contingency table (see Figure 1(a)) and in quantitative research by a scatter plot (see Figure 1(b)).

Figure 1 Examples of XY plots for NCA. (a) Contingency table with dichotomous qualitative scores when the presence of X is necessary for the presence of Y. The numbers in the cells are the number of cases with that XY combination. (b) Scatter plot with continuous quantitative scores when a high level of X is necessary for a high level of Y. Each dot is a case with a specific XY combination. Ceiling lines separate the area without data ('empty space') from the area with data ('feasible space') (see online version for colours)



(a) (b)

This summary assumes that the presence or a high level of condition (X) is necessary for the presence or a high level of outcome (Y). This means that the presence or a high level of Y is only possible when the condition is present or has a high level. If the condition is not present or does not have a high level, the presence or the high level of the outcome will not occur. Consequently, the upper left corner of the XY plot is expected to be empty. NCA evaluates bivariate relationships between condition(s) and outcome, as represented by contingency table or scatter plot. NCA draws a line over the data, rather than through the centre of the data. This line is called the ceiling line, shown in Figure 1. When the data are discrete the Ceiling Envelopment – Free Disposal Hull (CE-FDH) line can be selected, which is a step function (Figure 1(a), also shown in Figure 1(b)). When X and Y are (nearly) continuous the Ceiling Regression – Free Disposal Hull (CR-FDH) line can be selected, which is a straight line (see Figure 1(b)). This line is a trendline through the north-east edges of the CE-FDH line and is therefore not 100% accurate: some points are above the ceiling in the otherwise 'empty space'. The ceiling line facilitates the identification of the empty space in the upper left corner, signifying that achieving a high outcome level is virtually unattainable with a low condition level. Subsequently, the extent of this empty space is quantified to determine the necessity effect size. The necessity effect size quantifies the constraint the X poses on Y. When both X and Y are dichotomous (see Figure 1(a)) the necessity effect size can be only 0 (not necessary) or 1 (necessary). When both X and Y are trichotomous variables five effect sizes are possible: 0, 0.25, 0.5, 0.75 and 1 depending on whether 0, 1, 2, 3, of 4 upper left cells are empty. When both X and Y are continuous the necessity effect size can have a value between 0 and 1.

In quantitative research when probability samples from a population are analysed, NCA's statistical permutation test can be used to estimate the *p*-value associated with the effect size (Dul et al., 2020). This test limits the risk of drawing a false positive conclusion, namely that the effect size represents necessity whereas actually it is a random result of unrelated variables. Once one or more necessary conditions are identified, NCA's bottleneck table can be used to enable the formulation of necessity 'in degree' by assessing which condition levels are necessary for achieving specific outcome levels. The bottleneck table approach can also be used in qualitative research when the conditions are discrete with more than two levels. In qualitative research the data analysis to obtain the effect size can be done by visual inspection of the contingency table or by a simple calculation: [the number of empty cells in the upper left corner] divided by [the total number of cells, minus the number of cells from one column, minus the number of cells in one row, plus 1]. For quantitative research the complexity of the analysis requires use of free software packages, which are accessible for R and Stata users to facilitate the analysis.

NCA can be used as a stand-alone method in mono-method research or in conjunction with other methods in multi-method research. When combined with regression-based methods like multiple linear regression or Structural Equation Modelling (SEM), NCA offers new insights, highlighting that factors that may (or may not) on average effect the outcome are also necessary (or not) according to NCA. Richter et al. (2020, 2023) provide guidelines for incorporating NCA with Partial Least Squares Structural Equation Modelling (PLS-SEM). A basic version of NCA is included in the commercial Smart-PLS package for conducting PLS-SEM. NCA can also be effectively combined with Qualitative Comparative Analysis (QCA). The distinctions between NCA and QCA have been discussed in Dul (2016a) and Vis and Dul (2018), with NCA typically identifying more necessary conditions than QCA. NCA can be used with a deterministic causal perspective or with a non-deterministic causal perspective called 'typicality' allowing exceptions (Dul, 2024).

3 Sampling and sample size in qualitative NCA research

In qualitative research, usually a small number of cases is selected with a certain purpose. For example, researchers may want to select typical cases that represent a wider population of cases, deviant cases that are unusual or maximum variation cases that ensure maximum variation of a certain characteristic.

A different type of purposive sampling can be used for NCA. In this note it is assumed that the selected sample is representative for a wider group of cases to which the results are generalised. The specific goal of NCA is to test or explore a necessary condition. The necessary condition is expected to be present in nearly all cases that have the outcome and the outcome is absent in nearly all cases that do not have the condition. This means that in NCA cases can be purposively selected in two ways. Assuming that both the condition and the outcome are dichotomous variables (present/absent), the first approach is selecting cases where the outcome is present. If the necessary condition hypothesis holds, the condition must be present too. The absence of the condition rejects the necessary condition hypothesis: it is possible to have the outcome without the condition. The presence of the condition supports the hypothesis. The second approach is selecting cases where the condition is absent. If the necessary condition hypothesis holds, the outcome must be absent too. The presence of the outcome rejects the necessary condition hypothesis: it is possible to have the outcome without the condition. The absence of the outcome supports the hypothesis. Note that 'supports the hypothesis' means that the hypothesis is not rejected in the cases that were studied. This does not mean automatically that the hypothesis is 'true'. There may be other cases that were not selected that can falsify the hypothesis. Following replication logic, the confidence in the truth of a hypothesis increases when more cases do not falsify it. The number of cases for testing a necessary condition hypothesis this way can be relatively small.

In the deterministic view of necessity, the necessary condition is present in *all* cases that have the outcome and absent in *all* cases that do not have the condition. Consequently, for testing a necessary condition hypothesis a *single case* with the outcome, or a single case without the condition can be selected to falsify the necessary condition hypothesis. When a necessary condition exists only a small number of cases with the outcome can be selected to identify this condition. For example, following a Bayesian approach with dichotomous variables, Dion (1998) shows that with only 5 cases 95% confidence can be achieved that the necessary condition is supported. In a non-deterministic 'typicality' view of necessity some exceptions are possible. Although no generally accepted guideline exists for the maximum number of exceptions, an arbitrary maximum number of exceptions for considering a condition to be 'almost always necessary' could be 1 in 20, thus allowing 5% exceptions (Dul et al. 2010). Also, less strict suggestions have been suggested namely 15% (3 in 20) or 20% (4 in 20) in the context of QCA (Ragin, 2000, 2008). With a stricter number, the risk of drawing a false positive conclusion, namely concluding that the necessary condition exists when it does not exist, is reduced. The above approach works for dichotomous necessary conditions in which the condition and outcome can have only two values. With more discrete levels the approach is still possible but becomes more complex.

Purposive selection of cases where the outcome is present, or the condition is absent is not new. It has a long tradition in explorative and theory-building case study research. For example, Znaniecki (1934) introduced 'analytic induction' for finding causal relationships. This method identifies common characteristics in cases where the outcome is present, thus identifies necessary conditions (Robinson, 1951; Katz, 2001). Similarly, in political science, Dion (1998) discussed 'selecting on the dependent variable' in comparative case studies to capture necessary conditions. In theory-testing case study research, Dul and Hak (2008) described the method of testing necessity hypotheses by selecting cases where the outcome is present, or where the condition is absent.

An example of building necessary conditions with purposive sampling is a study by Harding et al. (2002), who studied rampage school shootings in the USA. They first selected two cases with the outcome (shooting cases) and identified five common characteristics as potential necessary conditions: gun availability, cultural script (a model why the shooting solves a problem), perceived marginal social position, personal trauma, and failure of social support system. Then, they selected two other cases with the outcome to verify if the conditions were also present in these cases and confirmed the earlier finding. In another example, Fujita and Kusano (2020) studied why some Japanese Prime Ministers (PMs) made highly controversial visits to the Yasukuni Shrine, by formulating three necessary conditions to decide to visit: a conservative ruling party, a government enjoying high popularity, and Japan's perception of a Chinese threat. They tested these conditions by considering all five cases where the outcome was present (PMs who visited the shrine) from all 22 cabinets between 1986 and 2014 and found that the three necessary conditions were present in all cases. Additionally, they selected the 17 cases where at least one potential necessary condition was absent and found in these cases the absence of a visit, giving further support for the findings.

In summary, with purposive sampling and dichotomous variables (e.g., with qualitative anchors like 'low' or 'high'), the sample size can be very small to build and test necessary conditions. Even with one case and a deterministic view on dichotomous necessity, a necessary condition can be falsified. Non-rejection gives support for the necessary condition and by replication with other cases, credibility for the necessary conditions increases if the findings are the same.

4 Sampling and sample size in quantitative NCA research

In quantitative research (e.g., regression analysis) the goal of sampling is to achieve a 'representative' sample by ensuring that each case from the population has the same chance of being selected for the sample. This 'probability sampling' approach makes it possible to statistically generalise the findings from the sample to the population. Probability sampling may not be realistic in practice, such that statistical generalisation is limited. NCA is not different than any other method in the assumption that a sample for statistical generalisation is a probability sample, e.g., that the cases are randomly selected from a defined population or that stratified sampling is employed. The general guidelines for good sampling also apply to NCA and are not discussed further here.

NCA's statistical test, which is a null hypothesis test (Dul et al., 2020), helps to avoid making false positive conclusions (Type I error): concluding that an observed empty space and its effect size is the results of necessity, when actually it is random result of unrelated variables. NCA's power test estimates the probability that the test falsifies the null hypothesis (p less than a selected threshold values, e.g., 0.05) when necessity exists in the population (to avoid Type II error).

The statistical power and sample size are closely related. Power is a pre-study characteristic, not a characteristic of the results of a study. It helps the researcher to evaluate if an intended sample size is large enough to be able to identify a necessary condition that exists. Being able to 'identify the necessary condition' means that the statistical test falsifies the null hypothesis (e.g., $p < 0.05$), while other conditions for concluding about necessity also apply, including theoretical support (necessity hypothesis) and a relevant necessity effect size. For example, a power of 0.8 indicates that for a given sample size (and other assumptions) the chance to identify the necessary condition is 80% if the condition exists in the population. In NCA the power depends not only on sample size but also on the true population effect size, the slope of the ceiling line and the true population distribution of the data under the ceiling line. However, these characteristics of the population are usually unknown, so they need to be assumed by the researcher. Statistical power in NCA also depends on the selected ceiling estimation technique, and the selected threshold p-value. NCA's power analysis is done for each necessary condition separately. It consists of a Monte Carlo simulation, as explained in Dul (2021).

Table 1 shows four examples of power estimations for two different distributions under the ceiling (uniform and truncated normal) and two different ceiling line estimation techniques (CE-FDH and CR-FDH). The uniform distribution represents a situation with more randomness (uncertainty) than the truncated normal distribution where the distribution depends on the mean and the standard deviation. For a power analysis the researcher must always make an assumption about the distribution of the data. In a regression-context, often a regular normal distribution is assumed, but this distribution cannot be used for NCA. By definition, the normal distribution can have values between minus infinity and plus infinity. However, NCA assumes bounded variables such that the normal distribution must be truncated. Since the researcher usually does not know the true distribution in the population, the assumption of the distribution is a weak spot in any power analysis.

Table 1 Power estimations with CE-FDH and CR-FDH for a linear population ceiling line with slope = 1 and two data distributions under the ceiling (uniform and truncated normal with mean 0.5 and standard deviation 0.2; same distribution for condition and outcome), and threshold *p*-value = 0.05. The *p*-value estimations are done with 1000 permutation samples and the power estimation is done with 1000 repetitions (resamples)

Power for CE-FDH – uniform					*Power for CR-FDH – uniform*				
(a)	*Effect size*				(b)	*Effect size*			
	0.05	*0.10*	*0.30*	*0.50*		*0.05*	*0.10*	*0.30*	*0.50*
Sample size 10	0.08	0.13	0.38	0.54	*Sample size* 10	0.08	0.12	0.36	0.48
20	0.13	0.25	0.77	0.90	*20*	0.10	0.20	0.67	0.86
50	0.36	0.72	1.00	1.00	*50*	0.14	0.34	0.99	1.00
100	0.76	1.00	1.00	1.00	*100*	0.15	0.50	1.00	1.00
200	0.99	1.00	1.00	1.00	*200*	0.14	0.68	1.00	1.00
500	1.00	1.00	1.00	1.00	*500*	0.11	0.92	1.00	1.00
Power for CE-FDH – truncated normal					*Power for CR-FDH – truncated normal*				
(c)	*Effect size*				(d)	*Effect size*			
	0.05	*0.10*	*0.30*	*0.50*		*0.05*	*0.10*	*0.30*	*0.50*
Sample size 10	0.07	0.05	0.20	0.50	*Sample size* 10	0.05	0.06	0.18	0.45
20	0.06	0.08	0.45	0.88	*20*	0.05	0.07	0.35	0.81
50	0.05	0.12	0.94	1.00	*50*	0.06	0.09	0.81	1.00
100	0.08	0.24	1.00	1.00	*100*	0.07	0.14	0.99	1.00
200	0.10	0.56	1.00	1.00	*200*	0.08	0.24	1.00	1.00
500	0.29	0.99	1.00	1.00	*500*	0.09	0.56	1.00	1.00

The tables show the power for six sample sizes ranging from 10 to 500 and four effect sizes: 0.05 (‘small’), 0.10 (‘small’ – ’moderate’), 0.30 (‘moderate’ – ’large’) and 0.50 (‘large’ – ’very large’). The selected ranges of sample sizes correspond to common effect sizes in empirical research with NCA. The selected effect sizes and verbal anchors are based on the general benchmark presented in Dul (2016b), which is often used in empirical studies to classify necessity effect sizes. The power of a study depends on several assumptions that the researcher must make explicitly. Based on the researcher’s assumption of the population distribution under the ceiling (uniform or truncated normal) and of the population effect size (ranging from 0.05 to 0.50), the table indicates which minimum sample size is required to be able to detect a necessary condition that is present in the population, with a likelihood that is mentioned in the cell. Often a likelihood of 0.8 is selected for a highly powered study. This means, for example, that for an assumed population effect size of 0.30, ceiling slope of 1, truncated normal distribution of points below the ceiling, and when using the CR-FDH ceiling line and a threshold *p*-value level of 0.05, the likelihood of identifying a necessary condition that is present in the population is 0.81 when the sample size is 50.

As expected, the power increases when sample sizes and effect size increase. The power is larger for a uniform distribution under the ceiling, compared to a truncated normal distribution. When the CE-FDH technique is used for identifying necessity, the power is usually higher than when the CR-FDH technique is used, in particular when the effect sizes are small.

The estimated numbers in Table 1 only apply to the described specific situation. For other situations (other slope of the ceiling line, other values of effect size and sample size, different distributions for X and Y, other threshold p value), the power of an NCA study can be estimated with the NCA software from version 4.0.0 in R using the function nca_power.

It is important to highlight two points about statistical power which are often misunderstood. First, even with a low-powered study it is possible to identify a necessary condition of it exists, but the likelihood to detect it (= power) is smaller than in a high-powered study. Second, once a study has been done and a *p* value is available, it makes no sense to perform a power analysis. Such post-hoc power analysis does not give new information compared to the information from the *p*-value (Lenth, 2001; Zhang et al., 2019).

In summary, with probability sampling in quantitative studies it is important to have a sufficiently large sample size to have a high chance that a necessary condition is identified if it exists. Small samples are possible if the expected effect size is large, but large sample sizes are needed for detecting small effect sizes. The power depends on several other characteristics that the researcher must assume. In general, the larger the sample, the larger the likelihood that a necessary condition is detected when it exists.

5 Conclusions

Although researchers often wish to receive specific recommendations for sample size, the decision about sample size remains a judgement by the researcher. Such judgement is not always easy. Many criteria must be taken into consideration, including the size and the variability of the population to which the results are generalised, the expected effect size, the type of research (exploration, first time theory testing, replication), the available resources, and the possible impact when an existing necessary condition is not identified. This Method note offers some principles and guidance for sample size decisions in quantitative NCA research, but it cannot make concrete recommendations that are generally applicable because of the above uncertainties.

In qualitative NCA research is it possible to select a small number of cases? When the condition and the outcome can have only two levels (e.g., low-high or absent-present), and a deterministic view on necessity is adopted, it is possible to falsify a necessary condition with a single case. In a purposive selected case where the outcome is present, the necessary condition is falsified if the condition is absent and not rejected when the condition is present. The credibility of the necessary condition finding increases when replications are done with multiple cases: the more cases the better.

It appears that NCA has relatively mild requirements for sample size as summarised by the phrase ‘at least one, but the more the better’. The small number of cases that are possible in qualitative studies might stimulate to application of NCA in qualitative research. Such NCA research is still under-represented in all available NCA studies and absent in the field of International Business and Management. A quantitative study with a sample size of 180 that is typical for IB&M research will probably have enough power to detect a necessary condition when it exists, but smaller sample sizes may also be sufficient as the power analysis suggests, and many studies have shown.

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