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Boolean comparative analysis of qualitative data
A methodological note

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Abstract. This paper explores the use of Boolean logic in the analysis of qualitative data, especially on the basis of so-called process theories. Process theories treat independent variables as necessary conditions which are binary rather than variable in nature, while the dependent variable is a 'final cause'. In this respect, Boolean comparison appears to be a rigorous method for testing process theories on the basis of qualitative evidence, for example, from case studies. It is argued that Boolean logic may compensate for some of the weaknesses of the conventional approach to process studies – going back to Stuart Mill's (1843) system of logic – by systematically comparing observations without forsaking complexity too much. In addition, Boolean logic systematically structures the kind of interpretive dialogue between theory and evidence typically found in qualitative research. Finally, a procedure for using Boolean analysis is outlined. This procedure involves systematic attempts to falsify and identify hypotheses on the basis of truth tables constructed from qualitative data.

Introduction

This paper explores the use of Boolean logic in the analysis of qualitative data in order to develop or test process theories. Process theories treat independent variables as necessary conditions which are binary rather than variable in nature, while the dependent variable is a 'final cause' (Mohr, 1982; Markus and Robey, 1988).

Methods for developing and testing process theories tend to rely on qualitative simulation analysis (Fishwick & Luker, 1991; Huff *et al.*, 1992), and especially on procedures for the analysis of qualitative data (e.g., Hardy, 1990; Johnson, 1987; Romme *et al.*, 1990). The use of qualitative data analysis, however, brings along an inherent tradeoff between reliability and validity (Miles & Huberman, 1984; Strauss, 1987).

Qualitative analysis of, for example, interview or documentary data intends to capture the underlying meanings and patterns embodied in the data. This kind of inductive analysis appears to address concerns for (external) validity, because by arguing from the parts to the whole the real meaning behind the data may emerge (Light, 1979). However, it also relies to a great extent on subjective interpretation and judgement, and thus introduces a tradeoff in terms of reliability. This problem can be somewhat reduced by using double coding procedures and other measures to cross-check potentially subjective interpretations (Strauss, 1987; Miles & Huberman, 1984). Nevertheless, the reliability of measures and conclusions obtained in the qualitative analysis of social processes tends to remain subject to severe challenge.

A general strategy for solving this problem involves building quantitative studies on formalizations of the qualitative (Smith, 1988). Following this strategy, Ragin (1987) introduced the method of Boolean comparison into social science research. The Boolean comparative method treats variables as binary entities, and can deal effectively with patterns of *multiple causation*, involving combinations of conditions producing a certain outcome. In addition, Boolean comparison generates explanations that account for every different combination of conditions. Boolean comparison may thus provide a rigorous method for testing process theories on the basis of qualitative evidence. The Boolean method has been applied in analyzing data on discrimination (Ragin *et al.*, 1984), analyzing ethnic political mobilization among territorially based linguistic minorities in Western Europe (Ragin, 1987), and analyzing self-organizing processes in top management teams (Romme, 1994). It is impossible to reproduce some of these applications in this short note, which intends to explore the use of Boolean analysis for developing and testing process theories.

The argument is organized as follows. The next section outlines the key differences between process and variance theories. Subsequently, we discuss how Boolean comparison may add to the conventional comparative methods used in process research, which rely on Stuart Mill's system of logic. Finally, some basic features of the Boolean approach to comparative analysis are described, and a procedure for applying Boolean analysis is outlined.

Process and variance theory

Most research in the social sciences can be classified as being based on either variance or process theory (e.g., Mohr, 1982; Markus & Robey, 1988; Harrigan, 1983). Following Mohr (1982), *variance* theories treat independent variables as both necessary and sufficient conditions for dependent variables to occur. The time ordering is largely immaterial; the outcome is the dependent variable. The researcher seeks to explain the variance in the dependent variable by an array of independent variables (Mohr, 1982). As such, variance theory tends to focus on testing propositions derived from general theories. Typically, this involves cross-sectional samples taken from large databases or populations. Variance theories therefore benefit from the use of multivariate and other sophisticated statistical techniques, which can be applied only to quantitative data (Harrigan, 1983). The major strength of these methods is that they produce generalizable results. However, limited explanations of the way specific, idiosyncratic phenomena arise can be provided (Harrigan, 1983).

In contrast, *process* theory treats independent variables as necessary conditions, and the variable as a 'final cause' (Mohr, 1982). In addition, variables are viewed as binary states rather than continuous scales. Process theory emphasizes invariant patterns of cause and effect over time as well as across different units. That is, constants are explained by combinations of other constants. For example, the dependent variable may be success versus failure of turnaround, and one of the independent variables (conditions) may be continuity in top-management positions versus appointment of new managers.

In process theories the goal of appreciating complexity is given precedence over the goal of achieving generality. As such, the case study method appears to be the main empirical instrument used by process researchers, because this method benefits from its attention to details in describing reality (Eisenhardt, 1989; Mintzberg, 1979; Yin, 1984). Case-oriented process research is to a large extent based on qualitative rather than quantitative data, especially because triangulation demands the blending and integrating of a variety of data and methods. For example, data from archival records and annual plans are compared with data collected from semi-structured interviews (Woodside & Heaps, 1992). The extensive use of qualitative data tends to generate problems in replicating and generalizing the results of studies that have adopted a process theory approach. Major advantages of this kind of approach involve access to multiple viewpoints (e.g., in the organization being studied) and relevance to management practice (Harrigan, 1983).

The contrast between the variance and process theory approach becomes clearer by looking at their underlying logic.[1] Several authors have pointed out that (process theory driven) case studies are based on experimental logic, also known as *replication* logic (Eisenhardt, 1989; Miles & Huberman, 1984; Yin, 1984). Replication logic suggests individual observations or cases should be considered as if they were single experiments, and the analysis should follow cross-experiment rather than within-experiment logic (Yin, 1984). Thus, one tries to reproduce findings in a new context or in another part of the data base (Miles & Huberman, 1984).

By contrast, the variance theory approach uses a *sampling* instead of replication logic. Whereas process theory is very much an evidence-oriented strategy, variance theory is more theory-centered. It is less concerned with understanding specific observations and more concerned with assessing the correspondence between relationships in large populations, on the one hand, and broad general theories, on the other. For example, studies focusing on the dynamics of social change typically start from process theory assumptions, whereas demographic forms of analysis are largely based on variance theory (Easterlin, 1980; Romme, 1990).

Process theory and Boolean comparison

The question now raised is 'How can process theories benefit from the use of the Boolean comparative approach?' The development of process theories generally relies on a limited number of observations or cases (Mohr, 1982). In addition, each subset of observations may involve another kind of phenomenon. As the number of observations decreases, the possibility of subjecting arguments to rigorous statistical testing diminishes. Other methods must then be used. Smelser (1976) argues the method of 'systematic comparative illustration' must be used when the number of relevant observations is small.

This method in fact goes back to Stuart Mill's (1843) system of logic, in particular his so-called 'direct method of agreement' and 'indirect method of difference'. Essentially, Mill's methods involve a search for patterns of invariance. In the method of agreement all instances of a phenomenon are identified, and the researcher attempts to determine which of the possible causal variables is constant across all instances (Ragin, 1987). Thus, a constant (e.g., successful turnaround) is explained with another constant (e.g., support of key stakeholders). The main problem with this method is its inability to establish any necessary link between cause and effect (Mill, 1843). For example, the fact that all instances of successful turnaround also display the support of key stakeholders does not guarantee that this support of stakeholders causes successful turnaround. Both stakeholder support and successful turnaround may result from some unidentified third factor, for instance, a certain sequence of managerial actions. Another problem with the method of agreement is its incapacity to deal with multiple causation, the possibility that the combination of several causes leads to successful turnaround.

Mill's (1843) indirect method of difference basically involves a double application of the method of agreement in order to establish patterns of invariance. Suppose the researcher believes that stakeholder support causes successful turnaround. First, the researcher identifies cases of successful turnaround to see if they agree in displaying stakeholder support. If they do, then instances of turnaround attempts that have not been successful are examined to see if they agree in displaying an absence of stakeholders' support. Ideally, the second set of cases – displaying an absence of both cause and effect – also provide a basis for rejecting competing hypotheses. Suppose that, for example, the cases displaying both successful turnaround and support of stakeholders also display high homogeneity of the management team, a possible explanation of successful turnaround. Then, in order to reject this particular explanation at least one of the cases displaying an absence of both stakeholder support and successful turnaround should display a high homogeneity of management.

In fact, the method of difference comes close to what is now known as a good experimental design, but it still suffers some of the same liabilities as the method of agreement in situations of multiple causation (Ragin, 1987). An additional weakness of the method of difference is the identification of negative cases. Negative cases – those where cause and effect are both absent – are often difficult to identify because the researcher should then broaden his population of cases to *possible* instances of the phenomenon of interest (Ragin, 1987). In the example given earlier, the researcher would have to identify cases involving turnaround attempts that were successful as well as cases that were not successful.

The method of agreement and the method of difference form the core elements in the way (preliminary) process theories are *generated* (Mohr, 1982; Strauss, 1987; Yin, 1984; Miles & Huberman, 1984). While they are useful especially as inductive techniques, both methods appear to be incapable of handling multiple causation as well as the identification of negative cases (Ragin, 1987). However, these methods remain popular because in practice they are not applied in a formal, rigid manner. In practice, the weaknesses of Mill's methods also provide opportunities for the development of new theoretical and empirical distinctions (e.g., Langley, 1989; Mintzberg & Waters, 1985; Hardy, 1990). For example, Hardy (1990) deals with unanticipated differences between cases of successful turnaround by differentiating types and assessing patterns of multiple causation. The methods of agreement and difference, therefore, provide rough guidelines for comparative research which is *inductive* in nature, especially for exploring the evidence.

Evidently, Mill's methods can not serve the purpose of testing theories about patterns of invariance characterized by multiple causation. At this point Boolean analysis appears to be very useful because it provides a formal instrument that can handle the problem of multiple causation as well as the identification of negative cases effectively.

How to apply Boolean comparison

This section outlines basic features of the Boolean approach to comparative analysis, and subsequently describes a procedure for using Boolean comparison. Boolean algebra provides what are today the standard logical definitions of AND, OR, etcetera. The Boolean principles used in qualitative comparative analysis are quite simple. They are easy to grasp because they are consistent with logical principles common to many types of research in the social sciences, and especially case study research (Yin, 1984). In the remainder of this section we assume readers have some elementary knowledge of Boolean logic.[2]

Boolean comparison is especially useful for the qualitative analysis of a number of cases. It pays attention to patterns of multiple causation (involving combinations of conditions) and produces explanations that account for every different combination of conditions. The results of comparative Boolean analysis are therefore affected by each logically different observation, and not so much by the frequency of their occurrence. In this respect, Boolean analysis fundamentally differs from multivariate analysis, which pays special attention to the variance between different observations as well as the frequency of their occurrence.

At first sight, Boolean analysis may seem to be a simple version of log-linear (e.g., probit) analysis. However, again note that Boolean analysis produces explanations that account for every different piece of data equally, whereas the results of log-linear analysis primarily account for the frequency of occurrence of each piece of data.

Boolean comparison can be used to address complex empirical phenomena, especially apparent in patterns of multiple causation – where different conditions combine in different and sometimes contradictory ways to produce the same or similar outcomes (Ragin, 1987). Given certain theoretical categories, Boolean comparison has a strong inductive element because it proceeds from the bottom up, simplifying complexity of the data in a systematic, stepwise manner. Assuming a certain amount of research has been done, including the development of theory and the construction of a qualitative database, the steps taken in Boolean comparative analysis are as follows (Romme, 1994; Ragin, 1987).

Hypotheses

Each hypothesis is described in terms of a set of conditions and outcomes. From these hypotheses the central theoretical categories can be inferred. Consider the following example. We assume that our initial hypothesis, formulated as a Boolean expression, is

$$BC + D \rightarrow A$$

where A refers to turnaround success, B to a certain sequence of managerial interventions, C to a high level of homogeneity of management, and D to the support of key stakeholders.

Truth tables

The qualitative data are transformed into truth tables. This transformation may involve extensive coding work (e.g., Romme, 1994; Strauss, 1987). A truth table shows primitive expressions using Boolean logic, which assumes there are two logical states of one single variable: 1 (presence or true) and 0 (absence or false). We will follow the convention of using uppercase letters to denote the presence of a certain condition and lowercase letters to denote its absence.

Table I provides an example of truth table results for B, C and D as conditions and turnaround success A as the outcome. Simple inspection of this table indicates that condition D, the support of key stakeholders, is the dominant cause of A.

Minimization of truth tables

Table I implies the existence of three combinations of conditions for A to occur:

$$bcD + bCD + BcD \rightarrow A$$

This expression shows that three combinations of conditions each produce successful turnaround: for instance, the first combination 'bcD' implies that successful turnaround occurs when the sequence of interventions is absent, the management team is not homogeneous, and stakeholders support the turnaround attempt.

Boolean minimization of a truth table produces a Boolean expression which reflects the minimum set of the 'existent' combinations of conditions for the dependent variable in the table. Minimization is the most fundamental procedure in Boolean analysis. It is a simple and straightforward method for simplifying the complexity of truth tables. The basic principle in minimization is: if two Boolean expressions differ in only one condition yet produce the same outcome, then the condition that distinguishes the two expressions can be considered irrelevant and can be removed. Thus, the so-called prime implicants of the dependent variable are obtained. Computation of the minimized truth table expression for Table I gives:

$$bD + cD \rightarrow A$$

Thus, bD and cD are the prime implicants, that is, they 'imply' the

Table I. Hypothetical truth table

Conditions				Number of instances	Existent/ non-existent
B	C	D	A		
0	0	0	?	0	N
0	0	1	1	2	E
0	1	0	0	1	E
0	1	1	1	1	E
1	0	0	0	2	E
1	0	1	1	2	E
1	1	0	?	0	N
1	1	1	?	0	N

A, turnaround is successful.
B, certain sequence of managerial interventions.
C, high homogeneity of management.
D, turnaround is supported by key stakeholders.

combinations *bcD*, *bCD* and *BcD*. Thus, the support of key stakeholders in combination with either the absence of certain interventions or the absence of high homogeneity of management leads to successful turnaround. This expression falsifies the hypothesized condition *BC*.

Selection of essential prime implicants

The essential prime implicants constitute the logically minimal conditions of the dependent variable. That is, they involve the sufficient and/or necessary conditions for this dependent variable. This step is important when the reduced truth table expression, obtained in the previous step, includes so-called cyclic combinations. Cyclic combinations involve a set of overlapping prime implicants which are not all needed to minimally cover the truth table. If the reduced expression obtained earlier does not include cyclic combinations (which is the case in the example given), the combinations of conditions in this expression provide the essential prime implicants.

Evaluation of results

Subsequently, the results obtained in the previous step are compared with the initial hypothesis. If this hypothesis is (partly) falsified, it may be useful to start again with the first step by reformulating the initial hypothesis, and so forth.

Introduction of simplifying assumptions

Boolean comparison avoids making simplifying assumptions at the outset. After having allowed for maximum causal complexity in the preceding steps, simplifying assumptions can now be introduced. This involves selecting combinations from the truth table that are not included in the Boolean expression(s) obtained earlier, and then adding these terms to the expression.

When we assume that combination BCD in Table I has a 1-term for A, which is a plausible assumption given our initial hypothesis, the minimized expression is further simplified to:

$$D \rightarrow A$$

Both the minimized truth table expression and the simplification of this expression falsify the combination BC as a proposed condition. The simplified expression identifies the support of stakeholders as a sufficient condition.

This simple example shows how Boolean comparison structures the dialogue between theory and data. Starting from a hypothesis that determines the minimum set of variables included in the analysis, Boolean comparison proceeds inductively by simplifying the complexity of the data in a systematic, stepwise manner.

Falsification and identification of hypotheses

In general, minimization of truth tables serves as a direct attempt to *falsify* (part of) the initial hypothesis, whereas the step of simplifying assumptions involves an attempt to *identify* the hypothesized conditions from the minimized expression. The attempt at falsification is a straightforward inductive procedure, completely in line with the definition of falsification in the philosophy of science (Popper, 1963).

The step of simplifying assumptions is especially important in view of the limited diversity of most truth tables. Limited diversity of the data included in truth tables may arise for two reasons. First, the set of existent cases in a truth table tends to be taken from a larger universe of actually existing cases (cf. limited variance of data in multivariate analysis). Second, this set of actually existing cases may be smaller than the total set of theoretically possible cases, as a result of institutional or evolutionary constraints. Thus, some of the non-existent combinations in Table I can be assumed to exist in reality (e.g., BCD), whereas other non-existent combinations are perhaps also completely absent in the real world (e.g., bcd).

These limitations place constraints on possibilities for testing causal arguments. As we saw earlier, this problem cannot be solved in the conventional comparative methods based on Mill's system of logic. Thus, simplifying assumptions may be introduced in order to make inferences about the larger universe of real-world and theoretically possible cases. Note that this approach is quite different from making general (statistical) assumptions at the outset. Simplifying assumptions enter the analysis only after maximum causal complexity has been allowed for. Thus, conclusions about the validity of a given hypothesis are based on the results *before* as well as *after* introducing simplifying assumptions.

Conclusion

Boolean analysis appears to provide a structured dialogue between data and theory, and thus reduces the traditional problem of reliability in case study research.

To some extent, Boolean comparison *selectively* unites certain elements of multivariate analysis and the case study method. The power of multivariate analysis especially lies in answering questions of general variations in large populations of organizations or other entities, within a given and clear conceptual framework defined in terms of dependent and independent variables. In common with this method, Boolean comparison appears to allow systematic assessment of a larger number of observations (Ragin, 1987). However, it does not incorporate the greater sophistication and intelligence of, for instance, multivariate techniques.

In common with the case study method, the Boolean approach allows assessment of complex patterns of causation, involving combinations of conditions producing outcomes which in turn can be conditions for other outcomes. Strictly speaking, Boolean comparison does not provide maximum attention to historical details, as case studies generally do, but it may alleviate some of the weaknesses of case studies, especially in terms of reliability and external validity. In this respect, Boolean comparison has a strong inductive element because it proceeds from the bottom up, by simplifying the complexity of the data in a systematic stepwise manner. In addition, by assigning cases to different sets of conditions, key cases and key combinations of conditions are simultaneously identified (Ragin, 1987; Romme, 1994). These cases and conditions can then be examined in more detail by returning to more detailed information about the cases, or by more focused follow-up studies. In sum, the kind of dialogue between theory and evidence which is typically found in studies of social processes may profit from Boolean comparison as a means to structure this dialogue in a systematic manner.

As also noted by Ragin (1987), Boolean techniques should therefore not be used mechanically, but as aids to interpretive analysis. The results of Boolean analysis do not take the place of interpretive analysis, but are means to carefully structure the large amounts of qualitative data usually produced by case studies. Furthermore, in most applications Boolean analysis will be one of the last steps in a broader plan of research activities (e.g., literature study, case studies, developing preliminary propositions). Limitations in some of the preceding steps may severely constrain the conclusions derived from Boolean comparison (Romme, 1994).

Case study research may especially benefit from the Boolean method if based on process-theory assumptions. The synergy between Boolean comparison and process theory is especially evident from the following four characteristics they have in common. First, Boolean comparison and process theory both give precedence to the goal of appreciating complexity over the goal of achieving generality. Especially when data are predominantly qualitative in nature, Boolean comparison may simplify the complexity of the data in a systematic manner. Second, they both treat independent variables as necessary (and not necessarily also sufficient) conditions. Boolean logic makes a clear distinction between necessary and sufficient conditions. Third, they both treat variables as binary states rather than continuous scales. Finally, both Boolean comparison and process theory emphasize invariant patterns of cause and effect over time or across different units. Thus, constants are explained by combinations of other constants.

The aim of this note was to describe Boolean comparison as a rigorous method for developing and testing process theories on the basis of qualitative evidence. In this respect, Boolean comparison compensates for some of the weaknesses of the conventional approach to comparative case studies by systematically addressing a larger number of cases without forsaking complexity too much. In addition, Boolean comparison systematically structures the kind of dialogue between theory and evidence typically found in process research.

Notes

1. Mohr (1982) also claims there is an additional difference between variance and process theories in their deterministic versus probabilistic nature. In this paper we disagree with this position for two reasons. First, much process theory building in the social sciences does in fact start from a deterministic approach (e.g., Mintzberg *et al.*, 1976; Hardy, 1990; Rokkan, 1970). Second, from a mathematical point of view, at least some of the aggregate relations typically regarded as probabilistic in nature can be explained by far-from-equilibrium models, also known as chaos theory. These models involve multiple deterministic equations of which at least one is non-linear in kind (Jantsch, 1980; Van Witteloostuijn & Van Lier, 1990).

2. Ragin (1987), Roth (1975) and McDermott (1985) provide introductions to the most important principles of Boolean algebra.

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