ALTERNATE APPROACHES TO ECOLOGICAL THEORY: LOGICAL AND SIMULATION ANALYSES*

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Organizational ecology (OE) has been highly successful in advancing our understanding of the dynamics of organizations and organizational populations. Although part of this success is due to the extensive empirical studies undertaken by ecological researchers, a key success factor in our view is OE's emphasis on "hard" theory. The research program in OE could be considerably enhanced by the use of two computer-supported methods of hard theory building – logical analysis and computer simulation.

The purpose of this paper is to discuss applications of logical analysis and computer simulation to theory building in organizational ecology. We first introduce each of these approaches and review their application to several issues of importance to organizational ecology. We then compare the two approaches. We conclude by identifying issues for which logical analysis is more likely to succeed, and issues that can be best studied by simulation methods. We also discuss the potential for advancing theory by combining the two methodologies.

Logical Analysis

Logical analysis starts with the choice (or design) of a formal language. Once the language is given the key claims of a theory can be translated into this language. To prove these claims one needs to identify and formalize the relevant definitions and assumptions. This is an important and creative process since neither the assumptions nor the definitions are explicit; to find them is a step in theory building. Inconsistency should be avoided – this is the phase where computers start to play a role, since consistency checks can be automatically generated, at least for simple languages.

Most logical attempts to reconcile theory fragments of OE used standard, classical first order (propositional) logic. Péli et al. (1994) examined organizational inertia, which provides justification for a selection-based ecological approach. They concluded that the semi-formal argument of Hannan and Freeman (1984) was not sufficient but can be saved by strenghtening the assumptions. Later, Péli at al. (2000) showed that there are at least three different ways in the classical framework to demonstrate that the original informal argument is indeed correct.

Péli (1997) reconstructed an important argument in OE concerning niche width. If we distinguish specialist and generalist organizations and accept the principle of allocation, it seems inevitable that specialists outcompete generalists. Yet Hannan and Freeman (1977) argued that in a periodically changing environment generalist organizations might be favored by selection under specific circumstances. Péli (1997) not only showed that their original line of argument is correct but specified necessary conditions for such an argument to work.

These efforts were motivated by asking whether the theory fragments in question are based on logically sound arguments; their contribution to theory building was a pleasant bonus. This situation changed with Hannan's (1998) work on reconciling four formal theory fragments describing age dependence in organizational mortality (the liabilities of newness, adolescence, obsolescence, and senescence), which cannot possibly all be true for all populations of organizations. The task for logical analysis is to reconcile these fragments and present a coherent and consistent picture of age dependence. Hannan (1998) managed to reconcile some of these theory fragments but not all of them.

To achieve this latter task, one has to leave the realm of classical first order logic. Using a non-monotonic logic developed for this purpose, Pólos and Hannan (2000) provided a coherent and consistent picture that incorporated all the theory fragments and yielded unexpected results. The picture that emerged in Pólos and Hannan (2000) is that, under typical circumstances, mortality first rises, than declines, and later rises again. Empirical support for this pattern of age dependence was then observed for the first time in a study by Dobbs and Harrison (2000).

The logic used by Pólos and Hannan (2000) appears to be the logic implicitly followed in theory building when the theory is in flux and reasoning is based on partial information. The development of user-friendly computational tools for this non-monotonic logic is a job for the future.

Computer Simulation

Computer simulations calculate system changes using numerical methods, freeing the researcher from the constraints of solving equations analytically or of discovering formal derivations for results. Simulations are usually used in organizational research to study the behavior of complex systems, or systems composed of multiple interdependent processes. Each of the individual processes is usually simple and straightforward, and is often well understood from previous research or at least well supported theoretically. But the outcomes of the interactions of the processes are not obvious.

For example, in a simulation of competition between organizational populations (Carroll and Harrison, 1994), one process was organizational failure, which can be specified using mortality rate equations. Other processes were the entry of new populations and organizational foundings within existing populations. The simulation demonstrated that under a wide range of conditions, there is a substantial likelihood that competitively inferior populations – that is, populations that are less efficient competitors in terms of their interpopulation competition coefficients – will outcompete competitively superior populations. This finding suggests that path dependence can play an important role in the evolution of organizational populations.

The theoretical rigor introduced by formal modeling is one of the strengths of simulation work. Formalizing processes imposes a discipline on theorizing, forcing researchers to come to grips with thorny issues that have previously been dealt with by "handwaving" or were not even recognized.

Simulation has been used to address a variety of ecological issues, including the evolution of organizational size distributions (Hannan and Ranger-Moore, 1990), the role of chance in population evolution (Hannan and Carroll, 1992; Carroll and Harrison, 1994), the role of entry and exit processes in producing strategic bifurcation in R&D-intensive industries (Lee and Harrison, 1997), the behavior of organizational growth models (Harrison, 1998), the relationship of organizational culture to the liability of newness (Harrison and Carroll, 1999), and the influence of observation plans on coefficient estimates for ecological models (Carroll, Hannan, Harrison, and Kinstlick, 1998). Many of these simulations rely on the equations of population dynamics previously developed in OE; the numerical methods of computer simulation allow their implications for an ecological system to be more fully examined free of the mathematical constraints of formal deductive reasoning.

Comparing Logical Analysis and Computer Simulation

Logical analysis and computer simulation have a number of similarities. They are both based on mathematical formalizations (with important differences). They both help to clarify the structure of theories. Both approaches rely on assumptions of theories, including functional forms specified in the theories. Both approaches can combine theoretical components into a broader theoretical framework, a form of theoretical synthesis. Both approaches are able to generate new theory, and both approaches have the potential to inform empirical research design.

The two approached also have significant differences, including:

- In logical analysis, the assumptions tend to address general relationships or system properties. In simulations, the assumptions tend to be precisely defined change equations, where much greater detail must be specified.
- The results of logical analysis tend to be general relationships, which can be viewed as constraints on the system being analyzed. The results of computer simulations tend to be precise time trajectories for system variables associated with specific parameter settings and other model features.
- Computational models can be developed without regard for the analytical constraints of mathematical derivation and proof. In logical analysis, analytical barriers may make it very difficult or even impossible to discover proofs for some valid relationships.
- Typically a theory is incompletely or ambiguously specified, requiring additional theorizing to complete the formal structure of the theory. In logical analysis, implicit assumptions may need to be made explicit and additional assumptions may be required to derive results. In simulation analysis, the functional forms for the theorized processes may need to be formally specified and other model components may need to be added to fully specify the system's behavior.
- Logical analysis often involves combining theory fragments – elements of the theory that apply under specified conditions and that may either complement one another or lead to competing predictions under some circumstances. In computer simulation analysis, several underlying processes need to be combined and integrated into a broader theoretical model.

Conclusion

Whether logical analysis and computer simulation are used to clarify existing theory, combine theoretical components, generate new theory, or inform empirical design, they can both produce unforeseen consequences.

Logical analysis seems to be particularly applicable when the *argumentation* that supports a particular theoretical claim is at stake. Since logic's primary goal to model (different) consequence relation(s), this might not be so surprising. Simulation analysis appears to be most useful for examining the *quantitative consequences* of the dynamic operation of a complex system and for exploring analytically intractable issues.

The potential exists for a productive interplay between logical analysis and computer simulation. Simulations can inform logical analysis by showing that specific sets of outcomes are *possible* in a given situation; this knowledge can provide the logician with some direction concerning what kinds of relationships to target for proof. Alternatively, logical analysis can inform simulation research by indicating boundary conditions for system behavior, permitting the simulator to focus on this region in a more productive and efficient fashion.